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Gasoline Taxes and Consumer Behavior†

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Gasoline taxes can be employed to correct externalities from automobile use and to raise government revenue. Our understanding of the optimal gasoline tax and the efficacy of existing taxes is largely based on empirical analysis of consumer responses to gasoline price changes. In this paper, we examine directly how gasoline taxes affect gasoline consumption as distinct from tax-inclusive retail gasoline prices. We find robust evidence that consumers respond more strongly to gasoline tax changes under a variety of model specifications. We discuss two potential reasons for our main findings as well as their implications. (*JEL* D12, H21, H25, H31, L71, Q35)

The gasoline tax is an important policy tool to control externalities associated with automobile use, to reduce dependency on oil imports, and to raise government revenue. Automobile use imposes externalities including local air pollution, carbon dioxide emissions, traffic accidents, and traffic congestion (Parry, Walls, and Harrington 2007). Although the gasoline tax is not the theoretically optimal tax for all of these externalities, a single tax avoids the need for multiple instruments (e.g., distance-based taxes and real-time congestion pricing) and offers an administratively simple way to control these externalities at the same time. Besides correcting environmental externalities, the gasoline tax can reduce gasoline consumption and may mitigate concerns about the sensitivity of the US economy to oil price volatility, constraints on foreign policy, and other military and geopolitical costs. Moreover, gasoline taxes at the federal and state levels are major funding sources for building and maintaining transportation infrastructure. Federal fuel taxes provide the majority of revenue for the Highway Trust Fund, which is used to finance highway and transit programs. Past increases in federal gasoline taxes have generated revenue for such programs, but the federal gasoline tax has stayed constant since 1993. Greater infrastructure investment needs and declining fuel tax revenues due

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to the recent economic downtown have led the Highway Trust Fund to be insolvent since 2008 and required Congress to provide funding from the General Fund.[1]

Growing concerns about climate change, air pollution, energy security, the national budget deficit, and insolvency of the Highway Trust Fund have brought renewed interests in increasing state and federal gasoline taxes. Understanding how gasoline tax changes affect automobile use and gasoline consumption is crucial in leveraging this instrument to achieve these policy goals effectively. An underlying assumption used in previous policy analysis on the effectiveness of higher gasoline taxes and the optimal gasoline tax is that consumers react to gasoline tax changes similarly to gasoline price changes. Consequently, the consumer response to oil-price induced changes in gasoline prices is often used as a proxy for the response to a commensurate change in the gasoline tax. The recent economics literature finds that consumers respond little to rising gasoline prices, at least in the short run.[2] Together with the maintained assumption, these estimates suggest that a large increase in the gasoline tax would be required to reduce significantly fuel consumption. Not only may this exacerbate the perceived political cost of increasing gasoline taxes, but it may explain partially why US policymakers have tended to favor less salient fuel economy standards over gasoline taxes, despite the broad conclusion of a large literature examining the Corporate Average Fuel Economy (CAFE) standards that gasoline taxes are more cost-effective at reducing gasoline consumption.[3]

The purpose of our paper is to quantify directly the consumer response to gasoline taxes. In contrast to the literature, our analysis estimates consumer responses to gasoline taxes explicitly by decomposing retail gasoline prices into tax and tax-exclusive components. Consumers may respond more to taxes than equal-sized changes in tax-inclusive gasoline prices because of perceived persistence and salience. Fixed costs of adjusting driving behavior and purchasing a car cause consumers to respond more to persistent than transitory gasoline tax or price changes. Furthermore, salience may be greater for a tax change than for an equal-sized price change, particularly given the much larger media coverage from tax changes that we document. Most tax changes are fairly small, typically less than \$0.10 per gallon. Consumers may be less aware of equal-sized gasoline price movements driven by oil price changes.

We use three outcomes to examine consumer behavior over short time horizons: gasoline consumption, vehicle miles traveled (VMT), and vehicle fuel economy (miles per gallon, MPG). VMT represents the intensive margin, MPG represents the extensive margin, and total gasoline consumption is the combination of the two. Our analysis employs two separate datasets: aggregate state-level data that allow us to examine responses in gasoline consumption, and household-level data that allow us to examine responses in VMT and MPG. We find that rising gasoline taxes are associated with much larger reductions in gasoline consumption than comparable

[1] In federal fiscal year 2010, \$51 billion of spending was committed from the Highway Trust Fund while the total revenue into the fund was just \$35 billion.

[2] A partial list includes Small and Van Dender (2007); Hughes, Knittel, and Sperling (2008); Bento et al. (2009); Li, Timmins, and von Haefen (2009); Klier and Linn (2010). These studies often use variations in gasoline prices driven primarily by supply and demand shocks.

[3] See, for example, Goldberg (1998); Congressional Budget Office (2003); Austin and Dinan (2005); Parry, Fischer, and Harrington (2007); Jacobsen (2013); and Anderson and Sallee (2011).

increases in gasoline prices; this result is robust across a variety of specifications and estimation methods. The results from our main specification suggest that a \$0.05 increase in the gasoline tax would reduce gasoline consumption by 0.86 percent, three times as large as the effect one would find from an empirical framework that does not separate gasoline prices into tax and tax-exclusive components. Dissecting the intensive and extensive margins, we find a significant differential effect in household MPG, especially among newer vehicles. Although we focus on short-term responses, the large effect of taxes on MPG suggests that the long-run response to taxes may also be greater than the long-run response to gasoline prices. Our analysis does not show a statistically significant differential effect on VMT from gasoline taxes and prices. This finding could be in part due to imprecise estimates and in part a reflection of the short-run focus of our analysis.

While adding to the extensive literature on automobile purchase and utilization cited above, our study also fits into the growing literature on how persistence, salience, and other factors may cause consumers to respond to one component of retail prices, such as a tax or rebate, differently from other components.[4] In the context of gasoline consumption, recent studies including Davis and Kilian (2011); Baranzini and Weber (2012); Rivers and Schaufele (2012); and Scott (2012) all provide evidence that consumers respond to gasoline taxes differently from other components. Baranzini and Weber (2012) examine gasoline demand in Switzerland using time-series data. Rivers and Schaufele (2012) use province-level panel data to investigate the consumer response to a carbon tax on fossil fuels in British Columbia, Canada. Finally, Davis and Kilian (2011) and Scott (2012) both employ US state-level panel data on gasoline consumption from 1989 to 2009.

Among the existing studies, our research is perhaps most closely related to Davis and Kilian (2011). Compared to estimates obtained via least squares, they report much larger effects (in magnitude) of gasoline prices when instrumenting with the state-level gasoline tax. They argue that the IV estimate should be interpreted as capturing the consumer response to the gasoline tax. Our research differs from their study in four important dimensions. First, our main goal is to estimate directly consumer responses to gasoline taxes. Our empirical analysis includes two price components—the gasoline tax and tax-exclusive price—which permits estimates of consumer responses to the two components. Rivers and Schaufele (2012) and Scott (2012) adopt a similar approach. In contrast, Davis and Kilian (2011) use the tax-inclusive gasoline price as the key regressor in the gasoline demand equation and use gasoline taxes as the instrument for the price variable. Nevertheless, their analysis does not produce an estimate of the elasticity of gasoline demand to gasoline taxes directly. Second, they use *monthly* state-panel data from January 1989 to March 2008 while our data are *annual* from 1966 to 2008. Therefore, their estimates may capture very short-term responses while ours represent effects over a longer term. Third, in addition to the gasoline consumption analysis using state-level data, we use household-level data to investigate the differential effect separately for the extensive and intensive margins. This analysis yields additional support for the finding of a

[4] For example, Busse, Silva-Risso, and Zettelmeyer (2006); Chetty, Looney, and Kroft (2009); and Finkelstein (2009); and Zheng, McLaughlin, and Kaiser (2012).

differential response and sheds light on the channels through which the differential effect arises. Lastly, we present a more detailed analysis on two potential reasons for larger responses to the gasoline tax: persistence and salience. The salience analysis is based on extensive data on media coverage of changes in gasoline prices and taxes.

Our main findings have several implications. First, they suggest that the gasoline tax would be more effective than the previous empirical literature has suggested at addressing climate change, air pollution, and energy security. 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 the external cost of greenhouse gas emissions. By focusing on the effects of gasoline taxes, our paper speaks directly to the effectiveness of these proposals.

Second, separating gasoline taxes from tax-exclusive prices may offer a strategy to address a challenging identification problem in environmental and energy economics. Energy efficiency-related policies such as CAFE are often advocated on the widespread belief that consumers use a high implicit discount rate to value future energy savings. Beginning with Hausman (1979) and Dubin and McFadden (1984), a large literature estimates the implicit discount rates consumers use to evaluate durable goods purchases. The identification problem arises because the econometrician does not observe a consumer's expectation of future energy prices. Consequently, it is impossible to estimate implicit discount rates without making assumptions on consumers' expectations of future energy prices. In some cases, assumptions of future expectations are innocuous (e.g., for regulated retail electricity markets) but in others, such as gasoline prices (which are subject to influences from numerous domestic and international factors), modeling consumer expectations is not straightforward.[5] Nevertheless, our analysis suggests that one could use state or federal taxes to estimate implicit discount rates without making assumptions regarding consumer expectations of gasoline prices. As we discuss, such an estimate would provide a lower bound to the extent to which consumers undervalue fuel savings.

Finally, the results have implications for the literature on the optimal gasoline tax (e.g., Parry and Small 2005). The literature estimates the optimal tax based partly on empirical estimates of the elasticity of gasoline consumption to gasoline prices, under the assumption that the gasoline tax and gasoline price elasticities of demand are the same. Our analysis focuses on short-term responses to gasoline taxes and tax-exclusive prices. Although we find evidence of differential responses in gasoline consumption from lagged tax and price changes, we leave the estimation of long-run responses for future research.

The paper proceeds as follows. In Section I, we present some background on US gasoline prices and taxes. We present our analysis of the aggregate state-level data in Section II and present our analysis of the household-level data in Section III. In Section IV, we discuss the implications of our results for the estimation of implicit discount rates and the elasticity of fiscal revenue. Section V concludes.

[5] Anderson, Kellogg, and Sallee (2012) offer an interesting look at consumer expectations of gasoline prices using survey data. We discuss their findings in relation to ours in detail in Section IIE.

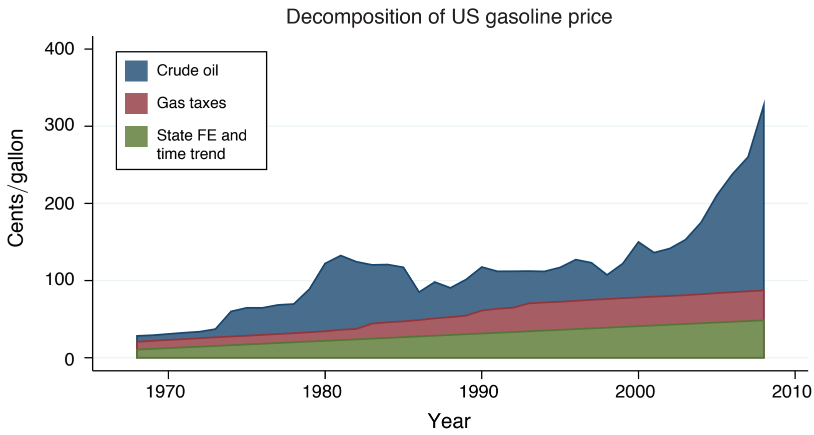

Figure 1. Gasoline Price Decomposition

Notes: Specification includes state fixed effect and a common linear time trend for all states. State-level data aggregated nationally.

I. Background on US Gasoline Prices and Taxes

Our empirical analysis employs changes in state gasoline taxes and tax-exclusive prices to investigate the effects of taxes on gasoline consumption, vehicles miles traveled, and vehicle choices. In this section, we discuss variation in US gasoline prices and taxes.

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

$$RetailPrice_{st} = \beta OilPrice_t + \gamma \tau_{st} + \alpha_s + \delta_s t + e_{st}, \tag{1}$$

where $RetailPrice_{st}$ is the retail price, $OilPrice_t$ is the crude oil price, and τ is the sum of federal and state excise taxes. The state fixed effects, α_s, 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. The coefficient on taxes is 1.03 and is statistically indistinguishable from 1, suggesting that gasoline taxes are borne heavily by consumers. This is consistent with the result in Marion and Muehlegger (2011), which finds that, under typical supply and demand conditions, state and federal gasoline taxes are passed fully on to consumers and are incorporated fully into the tax-inclusive price in the month of the tax change. Similar findings are also presented in Chouinard and Perloff (2004), Alm, Sennoga, and Skidmore (2009), and Davis and Kilian (2011).

Based on these estimates, Figure 1 decomposes the average US retail gasoline price 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 constitute a significant portion of the

Table 1—Nominal Prices and Taxes (cpg), over Time

Period	Average tax-inclusive retail price	Average state tax	Average federal tax	Tax fraction of retail gasoline price in percent	Percent of retail gas variation explained by tax changes
1966–1970	34.0	6.7	4.0	31.5	48.3
1971–1975	44.6	7.6	4.0	26.0	2.3
1976–1980	80.4	8.4	4.0	15.4	2.1
1981–1985	121.8	11.2	7.0	14.9	19.3
1986–1990	98.0	15.1	10.1	25.7	11.4
1991–1995	113.9	19.1	16.7	31.4	25.5
1996–2000	125.0	20.3	18.4	30.9	2.2
2001–2005	163.3	20.8	18.4	24.0	2.0
2006–2008	278.0	21.8	18.4	14.5	0.6

tax-inclusive gasoline prices for much of the period. Table 1 reports the average nominal gasoline price, state gasoline tax, and federal gasoline tax, in cents per gallon (cpg) for five-year intervals beginning in 1966 and ending in 2008. In addition, for each period the table reports the percentage of gasoline price changes explained by changes in gasoline taxes. The percentage varies substantially over time, rising with the federal gasoline tax (from 4 to 9 cpg in 1983, to 14.1 cpg in 1991, and then to 18.4 cpg in 1994) and state taxes, and falling during periods of high oil prices.

National averages obscure substantial cross-state variation in gasoline taxes. Figure 2 displays snapshots of per-gallon state gasoline taxes in 1966 and 2006. Figure 3 depicts changes in state gasoline taxes from 1966 to 1987 and 1987 to 2008. Figure 4 presents the mean, maximum, and minimum state tax as well as the federal gasoline tax over the period. Although the mean state gasoline tax rises slowly over time, state taxes rise more quickly in some locations than in others. In 1966, the difference between the states with the highest and lowest gasoline taxes was 2.5 cpg. In 2008, the difference was 30 cpg; Georgia's excise tax was 7.5 cpg while Washington's excise tax was 37.5 cpg.

States vary substantially in the frequency and magnitude with which they change gasoline excise taxes. From 1966 to 2008, state per-gallon taxes changed in about 26 percent of the state-years.[6] Gasoline taxes rose in 488 state-years and fell in 44 state-years, out of 2,064 total observations. Nebraska, North Carolina, and Wisconsin changed taxes most often, in 29, 24, and 24 years, respectively.[7] Georgia changed the gasoline tax only twice during the period.

Figure 5 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 1960s and late 1990s when oil prices were relatively low and taxes were relatively high. The proportion is lowest during the early 1980s and after 2005, when oil prices were high. At the peak in 1999, the proportion varies from a low

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

[7] 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.

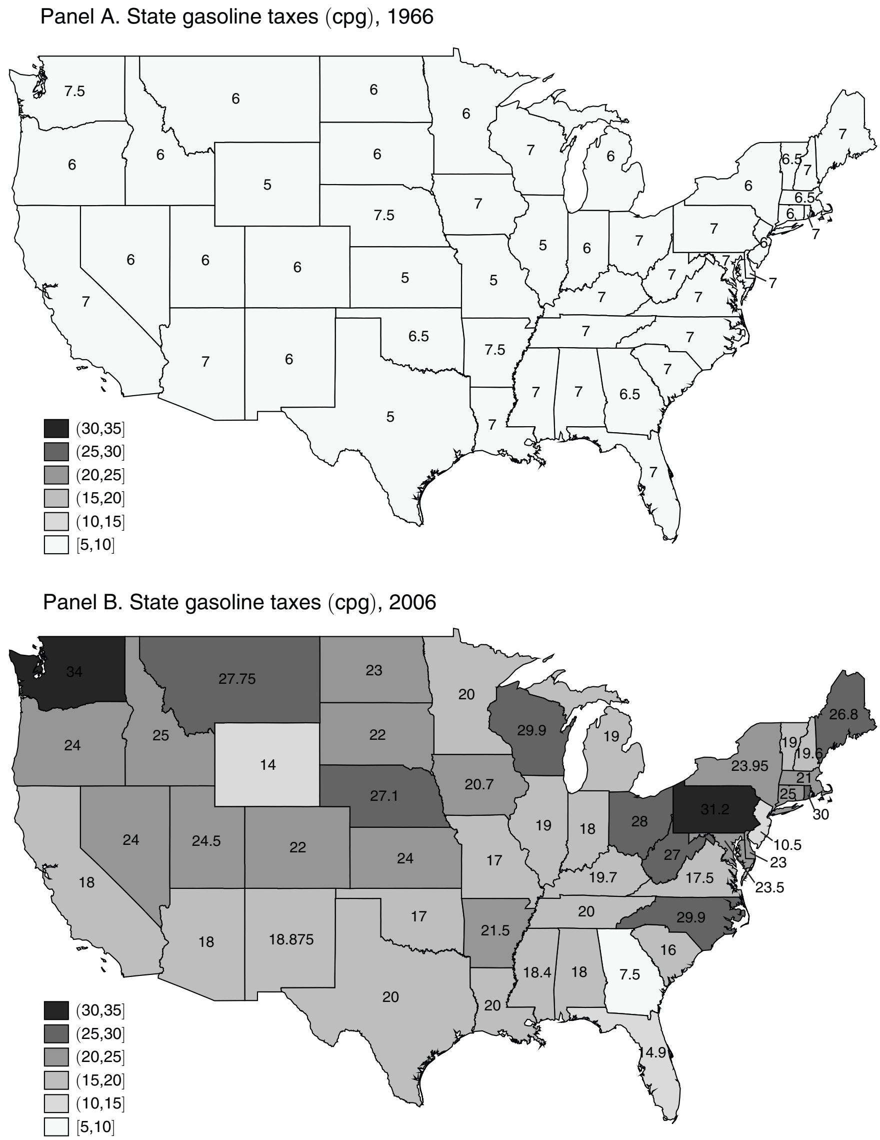

Figure 2. State Gasoline Tax Rates

of 25 to 30 percent (at the fifth percentile) to a high of over 40 percent (at the ninety-fifth percentile).

Although gasoline taxes constitute a large proportion of after-tax fuel prices, relatively little research examines political and economic factors that drive state and national fuel taxes.[8] The previous literature identifies a number of political and economic factors that correlate with fuel tax changes, such as road revenues from other sources (Goel and Nelson 1999), environmental regulation and trucking industry employment (Decker and Wohar 2007), and government debt as a percent

[8] See, e.g., Goel and Nelson (1999); Hammar, Lofgren, and Sterner (2004); and Decker and Wohar (2007).

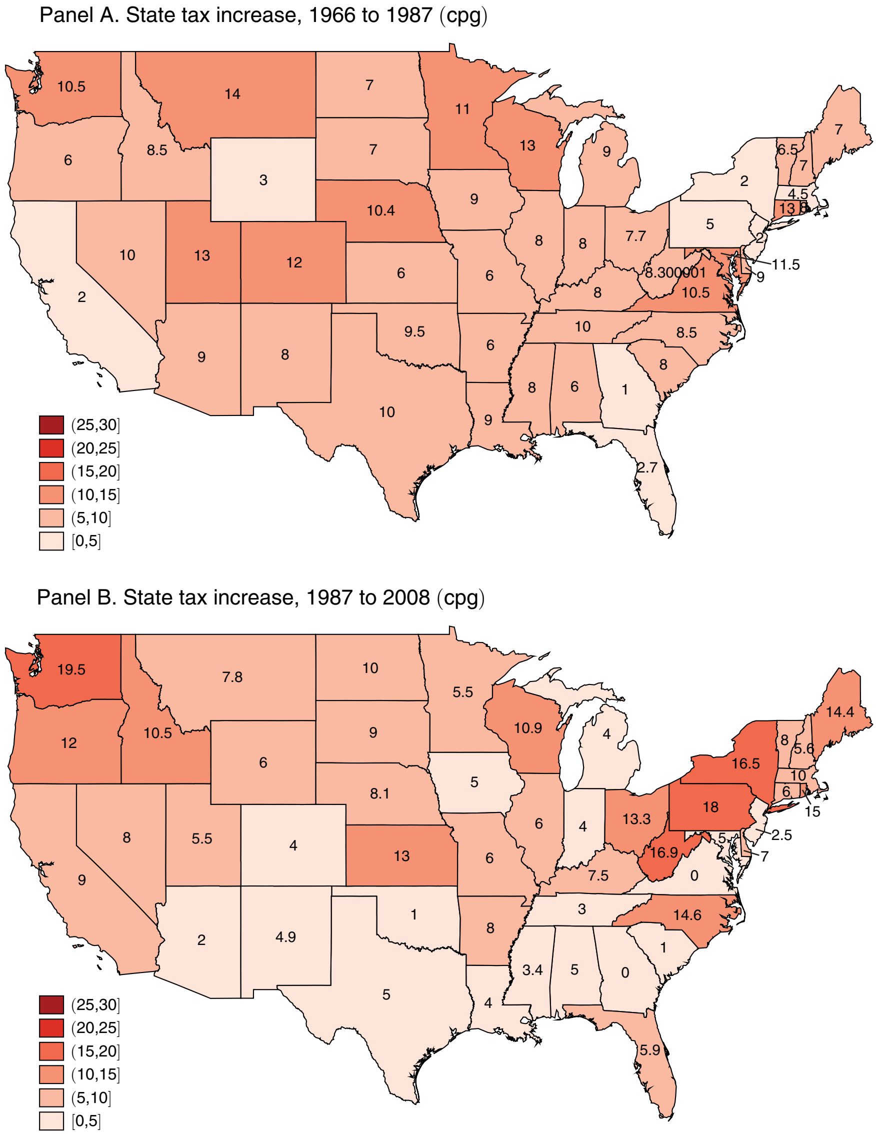

Figure 3. State Gasoline Tax Rates

of gross domestic product (Hammar, Lofgren, and Sterner 2004). Finally, Doyle and Samphantharak (2008) use gasoline tax moratoria that were granted in Illinois and Indiana in 2000 to estimate the incidence of gasoline taxes. Although in this case taxes were waived because of high gasoline prices, gasoline tax moratoria are very rare and constitute a negligible fraction of the variation in our sample. Overall, the past literature identifies political and economic factors correlated with tax changes, but the variables considered explain only a small fraction of total variation. We provide similar findings in our analysis below.

The gasoline tax literature has failed to identify political and economic factors driving gasoline taxes. We have collected 14 case studies to further investigate the

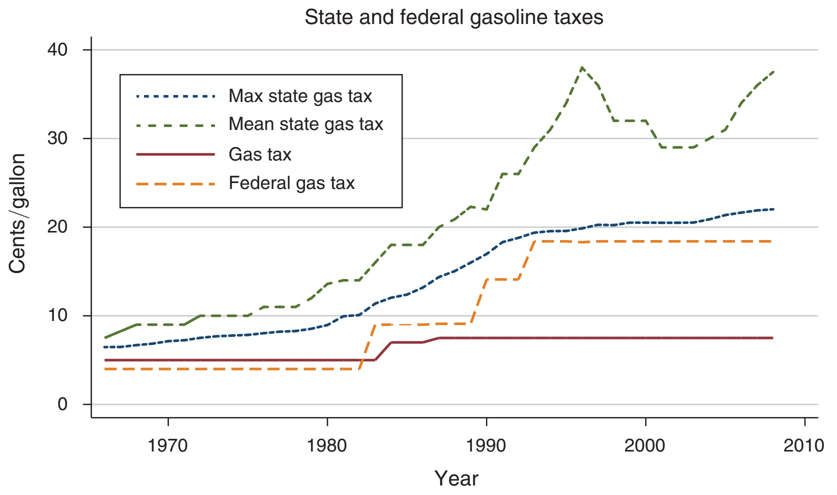

Figure 4. Distribution of Gasoline Taxes, by Year

sources of tax variation in our data. These include the eight case studies described in Watts, Frick, and Maddison (2012) and six recent tax changes observed in our data. The states represented in these case studies lie in different regions, have different political makeups, have different initial tax rates, and have different demographic trends. The case studies include Idaho, Indiana, Massachusetts, Minnesota, New Hampshire, New York, Oregon, Pennsylvania, Rhode Island, Utah, Virginia, Vermont, Washington, and Wisconsin.

Several patterns emerge from these case studies. First, the debate over changing the state gasoline tax typically preceded action by at least several years. The debate often begins with a report by a state agency or other organization that describes a large and long-term difference between the perceived needs for transportation infrastructure improvements and forecasted available funds. The gap between needs and funds can arise for a variety of reasons such as changes in population, business activity, or aging structures. Occasionally, a major disaster such as a bridge collapse sparks the debate. Debate often continues for several years after the precipitating event, until the state legislature and governor decide whether to change the tax (state referenda are less common). If the state changes its tax, the change is usually not immediate and it is phased in over several years. For example, in 2013 Maryland enacted a tax increase that will phase in by 2015 (this tax change is not part of our dataset, which ends in 2008). Another example is Washington, which passed a law in 2005 to increase the tax 9.5 cents over three years.

Second, there is typically a substantial amount of media coverage as the state government deliberates. News articles usually mention the current level of the state gasoline tax and the level that would exist if the proposed law is enacted. Because of the lag between delay and implementation, the media accounts inform consumers about changes before they occur. We document the extent of media coverage below.

The third pattern is that many states index their taxes rather than fixing the rate (ITEP 2011). Starting in the late 1970s, certain states indexed their taxes to the consumer price index, wholesale gasoline price, or retail gasoline price. Many

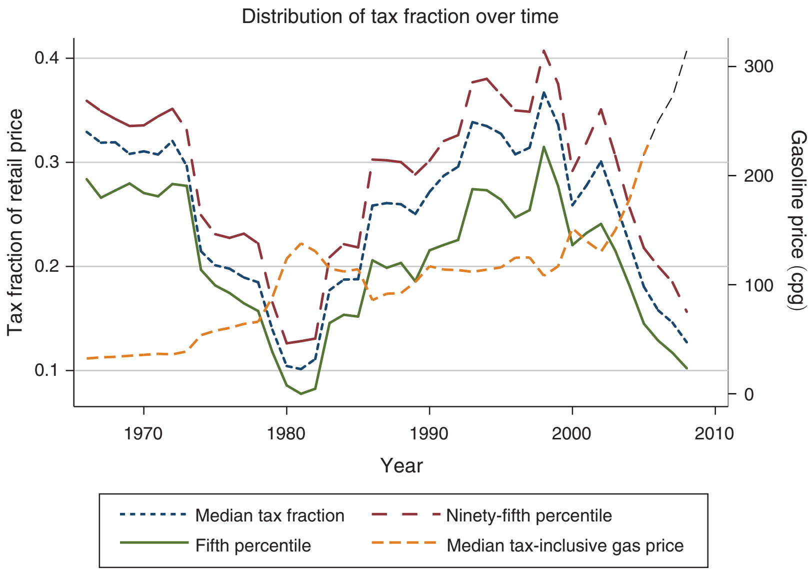

Figure 5. Tax Fraction of Retail Price, by Year

states adjust tax rates quarterly or every six months. In some cases the tax includes a fixed-rate portion and a variable-rate portion that is adjusted regularly; in other cases, the entire tax is indexed. Starting in the late 1980s, however, many states that had adopted an indexed tax reverted to a fixed-rate tax. Lawmakers and voters stated a variety of reasons for this reversal; for example, in Wisconsin, concerns that market forces rather than the state legislature set the tax rate ostensibly caused the state to return to a fixed-rate tax. Declining and low oil prices between the mid 1980s and late 1990s caused many states that indexed the gas tax to wholesale or retail prices to eliminate their variable taxes.

II. Aggregate Data Analysis

In this paper, we examine two distinct data sources: (i) aggregate data including gasoline consumption, taxes, and prices at the state level; and (ii) household-level data on vehicle ownership and driving decisions. We employ the aggregate data to estimate gasoline consumption responses to tax and price changes, and we use the household-level data to examine the extensive margin (vehicle choice) and the intensive margin (vehicle usage).[9] In this section, we present our empirical strategy, data, and results using the aggregate data.

A. *Empirical Methodology*

To compare the effects of gasoline taxes and tax-inclusive gasoline prices, we employ a similar empirical approach to Marion and Muehlegger (2008). We estimate

[9] Although state-level VMT measures are available, we do not use them to examine the intensive margin because of their well-known measurement errors.

the following linear equation, which decomposes the tax-inclusive retail price into a tax-exclusive component and the excise tax rate (which does not include ad valorem taxes):

$$(2) \qquad \ln(q_{sy}) = \alpha \ln(p_{sy}) + \beta \ln\left(1 + \frac{\tau_{sy}}{p_{sy}}\right) + X_{sy}\Theta + \delta_s + \phi_y + e_{sy},$$

where q_{sy} is the dependent variable, gasoline consumption per adult, by state (s) and year (y); p_{sy} is the tax-exclusive gasoline price; τ_{sy} is the total state and federal gasoline tax; X_{sy} is a vector of state-level observables; and δ_s and ϕ_y are state and year fixed effects. Within-state deviations from the national trend identify the correlation among the dependent variables, tax-exclusive gasoline prices, and tax ratios.

Following the above decomposition, we can derive the price and tax elasticities of demand from the coefficients in equation (2). Our analysis in the previous section as well as that in Marion and Muehlegger (2011) provide strong evidence that state taxes are passed fully (and rapidly) on to consumers. Under the assumption that consumers bear the entire tax, the tax-exclusive price is not affected by a change in the tax rate, and $dp/d\tau$ is equal to zero. With this assumption, equation (2) provides a direct test of whether taxes are more strongly correlated with behavior than are tax-exclusive gasoline prices. If consumers respond equally to changes in the gasoline tax and tax-exclusive price (of the same size), α should be equal to β.[10] In the empirical analysis, we test this equality explicitly and subsequently compare the effects of the gasoline tax and the tax-inclusive price. On the other hand, if, and only if, consumers respond more to a tax change than to a change in the tax-exclusive price—i.e., $\left(\left|\frac{\partial \ln(q)}{\partial \tau}\right| > \left|\frac{\partial \ln(q)}{\partial p}\right|\right)$—it can be shown that β should be larger than α in magnitude.

B. *Sources*

We use a panel dataset on gasoline consumption, gasoline prices, and state and federal gasoline taxes by state-year from 1966 to 2008. The data are taken from annual issues of the Highway Statistics, published by the Federal Highway Administration. Tax-inclusive retail gasoline prices are from the Energy Information Administration State Energy Price Reports. The data contain demographic variables, including population and average family size from the Current Population Survey, Bureau of Economic Analysis (BEA), and the census; and per capita income, gross state product, and fraction of the population living in metropolitan statistical areas (MSAs) 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 from the Highway Statistics reports: the number

[10] To see this, we take the derivative of equation (2) with respect to the tax-exclusive price and obtain: $\frac{1}{p}\left(\alpha - \beta \frac{\tau}{p + \tau}\right)$. Under the assumption that $dp/d\tau$ is equal to zero, taking the derivative of equation (2) with respect to the tax yields: $\beta \frac{1}{p + \tau}$. If α is equal to β, the two semi-elasticities are equal.

TABLE 2— ESTIMATION RESULTS FROM GASOLINE CONSUMPTION REGRESSIONS

	Specification 1		Specification 2		Specification 3		Specification 4	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A. Coefficient estimates								
log(gas price)	−0.060***		−0.192***		−0.157***		−0.097**	
	(0.009)		(0.061)		(0.048)		(0.037)	
log(tax-excl. = price)		−0.078***		−0.207***		−0.163***		−0.113***
		(0.010)		(0.061)		(0.048)		(0.038)
log(1 + tax ratio)		−0.331***		−0.765***		−0.470***		−0.292***
		(0.040)		(0.176)		(0.086)		(0.084)
p-value: $\alpha = \beta$		< 0.001		< 0.001		< 0.001		0.009
Panel B. Percent changes in gas consumption from a \$0.05/gallon increase in gasoline price								
Gas price	−0.203***		−0.566***		−0.468***		−0.286***	
	(0.027)		(0.180)		(0.141)		(0.109)	
Panel C. Percent changes in gas consumption from a \$0.05/gallon increase in gasoline tax								
Gas tax		−0.979***		−2.263***		−1.391***		−0.864***
		(0.118)		(0.520)		(0.254)		(0.248)
p-value: equal effects in panels B and C		< 0.001		0.002		0.002		0.033
State FE	X	X	X	X	X	X	X	X
Year FE			X	X	X	X	X	X
Covariates					X	X	X	X
State quadratic trend							X	X
R^2	0.756	0.777	0.897	0.905	0.942	0.944	0.973	0.973

Notes: The dependent variable is log(gasoline consumption per adult), by state and year. The number of observations is 2,064 in all regressions. Standard errors in all columns are clustered by state. Covariates include average family size, log road miles per adult, log number of registered cars per capita and log number of registered trucks per capita, log number of licensed drivers per capita, log real income per capita, fraction of the population living in metro areas, and fraction of population living in metro areas with rail transport. Panels B and C report percent changes in gasoline consumption from a \$0.05/gallon increase from either overall gasoline price or gasoline tax based on estimates in columns 1–8 of the five specifications in the table. The estimates use the average tax and tax-exclusive gas price in 1988 (24.1 cpg and 69.2 cpg), inflated to 2008 US dollars, the last year of our sample.

***Significant at the 1 percent level.

**Significant at the 5 percent level.

*Significant at the 10 percent level.

of licensed drivers, number of registered cars and trucks, and miles of public roads. Except for the federal gasoline tax, all variables vary by state and year.

C. *State-Level Gasoline Consumption Results*

Table 2 presents the main coefficient estimates in equation from eight regressions. The dependent variable is gasoline consumption per adult in logarithm and the key variables of interests are the price and tax variables. These eight regressions are grouped into four specifications where we add successively more control variables. Columns 1 and 2 (specification 1) include only state fixed effects while columns 7 to 8 (specification 4) include the most: state fixed effects, year fixed effects, and state-specific quadratic trends. Because the specifications include different controls, different sources of variation identify the coefficients on the tax-exclusive price and tax variables. For example, while specification 1 uses mainly temporal price and tax variations, specification 4 uses only time-varying deviations from the state average and state trend.

Columns 1, 3, 5, and 7 of Table 2 report estimates using the tax-inclusive gasoline price as the main regressor for the purpose of comparison. Adding year fixed effects decreases the estimate of the price coefficient dramatically from column 1 to 3, suggesting the national-level factors (as captured by year fixed effects) as an important source of price endogeneity. Column 5 adds a set of demographic variables that are commonly used in the literature (e.g., Small and Van Dender 2007). Column 7 further adds state-specific quadratic time trends. The specification in column 7 provides an estimates of -0.10 for the price elasticity of gasoline consumption.

This estimate is broadly consistent with previous results from the literature. Small and Van Dender (2007), with a shorter sample (1966–2001) of state-level data and using a different estimation strategy, obtain estimates of -0.09 to -0.17 for the price elasticity of gasoline consumption. Using monthly data at the national level, Hughes, Knittel, and Sperling (2008) find that the price elasticity ranges from -0.21 to -0.34 during 1975–1980 and from -0.034 to -0.077 during 2001–2006. Espey (1998) provides a broad review based on hundreds of gasoline demand studies; the short-run price elasticity ranges from 0 to -1.36 with a median of -0.23 based on 363 estimates.

Columns 2, 4, 6, and 8 in Table 2 separate the gasoline price into the tax-exclusive price and tax components. The estimates vary across the regressions but in all four cases, the coefficient estimate on the tax variable is much larger than that on the tax-exclusive price. The hypothesis that the two coefficients are equal can be rejected at the 1 percent significance level (p-values are provided in the table).[11]

Because of the strong persistence of gasoline prices, taxes, and consumption, we also estimate equation (2) using feasible generalized least squares (FGLS) in which we allow for a state-specific first-order autocorrelation structure in the error term. The standard errors are robust to heteroskedasticity and correlation within states. We do not report these results to save space but allowing for first-order autocorrelation has virtually no effect on our results compared with those from our main specification. Therefore, we use the regressions in columns 7 and 8 as our benchmark regressions through the text.

The coefficient estimates on the other variables (not reported but available upon request) are intuitively signed when precisely estimated. The short-run income elasticity, in line with the literature, is estimated to be 0.25 from the main specification and ranges from 0.22 to 0.33 across columns 5–8. The income elasticity estimate from Hughes, Knittel, and Sperling (2008) ranges from 0.21 to 0.75 across model specifications. In the review by Espey (1998), the median short-run income elasticity is 0.39 with a range from 0 to 2.91 based on 345 estimates. The parameter estimates across the specifications suggest that gasoline consumption increases with car ownership and the number of drivers. Interestingly, the estimated effect of the access to light rail on gasoline consumption becomes negative only when state-specific trends are included in columns 5–8.

Hughes, Knittel, and Sperling (2008) find that the price elasticity of gasoline demand decreased from late 1970s to early 2000s by comparing the estimates from

[11] The hypothesis that consumers respond more strongly to the gasoline tax than to the tax-exclusive price ($\beta > \alpha$) cannot be rejected at any conventional significance level.

two five-year periods in 1975–1980 and 2001–2006. In the same spirit, we have estimated separate coefficients on the tax and tax-exclusive variables by five-year time periods and find that, in five of the nine time periods, the coefficient on the tax variable is larger in magnitude and the difference is statistically significant. Although the tax variable is still larger in magnitude in the remaining time periods, the difference is not statistically significant (see online Appendix Table 1). In principle, the difference between the effects of taxes and tax-exclusive prices could arise because the coefficients are identified by variation in different time periods, but these results suggest that is not the case.

To assess the magnitude of the coefficient estimates on the price and tax variables, we calculate the percent change in gasoline consumption from a \$0.05 per gallon increase in gasoline price or tax. In doing so, we use the average price and tax in 1988, the year which matches the means over the sample period most closely. Panels B and C in Table 2 report the results corresponding to the five specifications in the first panel. The percent change in gasoline consumption from a \$0.05 per gallon increase in (tax-inclusive) gasoline price in column 1 is based on parameter estimates in column 1 while the effect from a \$0.05 per gallon increase in gasoline tax is based on parameter estimates in column 2. The results presented in column 5 are based on our benchmark regressions. Across all five columns, the effect from the change in gasoline tax are at least three times as large as that from the change in gasoline price.

One may be interested in comparing semi-elasticities for the tax-exclusive price and the tax. However, the comparison in panels B and C in Table 2 is much more informative to the policy and economic questions discussed in the introduction because the literature has focused on the tax-inclusive price elasticity. The parameter estimates themselves in Table 2 also suggest that consumers respond more to the tax than the tax-exclusive price. Because the semi-elasticity to the tax-exclusive price is not statistically significant, we do not focus on those results.

D. *Identification and Additional Tests*

We perform a host of additional analyses to examine alternative explanations for the estimated difference in the coefficients on the tax-exclusive gasoline price and the tax rate. We have assumed that the tax-exclusive price and tax rate are exogenous to other determinants of gasoline consumption. In the following, we first investigate the exogeneity of gasoline taxes by examining how the gasoline tax changes are determined. We then show additional regression results to examine the robustness of our finding to different modeling approaches.

Exogeneity of Gasoline Taxes.—To examine the exogeneity of the gasoline tax, we show that, after including state and year fixed effects (which are also included in the gas consumption regressions), economic and political variables do not predict state gas tax changes. We regress year-to-year changes in nominal state gasoline taxes (per gallon) on first-differenced economic and political variables. We include socioeconomic variables (e.g., gross state product (GSP) per capita, unemployment, urbanization, and educational attainment), political variables (e.g., League of Conservation Voters scores for a state's congressional delegation, a dummy for a governor belonging to the Democratic Party, the fraction of a state's house and senate seats occupied by Democrats, and a state's budget surplus as a fraction of revenues), and industrial variables (e.g., manufacturing and mining GSP shares). Table 3 presents the results. Specifications 1–3 cover the full sample. Specifications 4–6 use a shorter sample, but include several additional industrial and political variables. The three columns, for both samples, regress the change in state gasoline taxes on lagged, contemporaneous, and leading changes of the explanatory variables. Across the six specifications, the only significant, consistent correlation we find is that past and current and changes in state GSP are negatively correlated with gasoline tax changes (recall that the main regression model controls for GSP).[12] Collectively, the political and economic variables explain little of the variation in gasoline prices beyond what is explained by year fixed effects. The dependent variables are not jointly significant in any of the six specifications.[13]

The results in Table 3 suggest that tax changes are not correlated with observable socioeconomic, political, and industrial variables. Based on the state gas tax case studies mentioned above, there are several reasons state gas tax changes are unlikely to be correlated with unobserved factors that are, themselves, correlated with gasoline consumption. First, the lag between the beginning of the public debate and the eventual tax change reduces potential concerns that gas taxes may be contemporaneously correlated with other variables affecting gasoline consumption. For example, in principle gasoline tax increases could be more likely to pass a state legislature when the state economy is expanding. Even if this is true, the phase-in period reduces the possibility that tax changes are correlated with the business cycle.

Second, the fact that gaps between transportation funding and infrastructure needs motivate many tax increases also reduces concerns about a contemporaneous correlation between gas taxes and other variables. Population, long-run economic growth, and land development are major contributors to these gaps, and these variables tend to vary gradually over time. Quadratic time trends used in the estimation are likely to control for these variables, which allows us to identify the effect of tax changes from discrete tax changes rather than long-term trends.

Third, during the public debate over a potential tax change, media accounts usually mention both the current level of the tax and the level of the tax if the tax change occurs. These accounts therefore provide consumers information about the level of the tax prior to and after the tax change occurs, increasing the salience of the tax change. In other words, although many consumers may not know the level of the state gas tax when the tax is constant, media accounts provide information about the pre- and post-change tax levels, which increases saliency of the tax changes. We document media coverage below when we discuss saliency as a possible explanation for the large tax effects.

[12] As an alternative specification, we regressed on the same first-differenced explanatory variables a dummy variable for whether state gasoline taxes rise year-on-year. We do not find consistent significant correlations between the explanatory variables and the timing of state gasoline tax increases.

[13] Another possible source of tax endogeneity is that a state may set taxes to meet a revenue target. However, the small number of tax decreases in our dataset suggests that this is not common.

TABLE 3—GASOLINE TAXES AND POLITICAL ENVIRONMENT

	Explanatory variable, 1966–2008			Explanatory variable, 1985–2008		
	Lagged	Contemp.	Leading	Lagged	Contemp.	Leading
GSP per capita (000s)	−0.164***	−0.107**	−0.026	−0.120*	−0.0954**	−0.017
	(0.0564)	(0.0430)	(0.0495)	(0.0603)	(0.0472)	(0.062)
Mean family size	−0.0377	0.105	−0.169	−0.0113	−0.683	−0.595
	(0.246)	(0.163)	(0.213)	(0.474)	(0.443)	(0.429)
Autos per capita	0.269	0.751	−0.125	0.538	−0.505	−0.427
	(0.903)	(0.642)	(1.013)	(1.038)	(0.757)	(0.992)
Drivers per capita	0.471	−0.655	−0.314	0.382	−0.526	−0.912
	(0.852)	(0.535)	(0.761)	(1.164)	(0.749)	(0.938)
Fraction of adults graduating high school	0.0885	0.00714	0.0286	0.0808	−0.0644	−0.030
	(0.0893)	(0.0860)	(0.0734)	(0.155)	(0.148)	(0.142)
Fraction of adults with BA	−0.0557	−0.113	−0.131	−0.112	−0.249	−0.210
	(0.281)	(0.208)	(0.198)	(0.365)	(0.305)	(0.326)
Urban population share	−8.958	−11.05	−11.13	11.86	−7.765	−31.50*
	(9.594)	(9.127)	(8.595)	(15.93)	(15.75)	(17.85)
Population share in MSA with rail	−0.573	0.195	1.514**	0.350	0.176	1.244
	(0.529)	(0.844)	(0.713)	(3.239)	(1.228)	(1.153)
Democrat governor	0.0951*	0.0847	0.0048	0.0645	0.0697	0.037
	(0.0524)	(0.0815)	(0.0621)	(0.0689)	(0.117)	(0.100)
Fraction of Democrats in state senate	−0.166	−0.312	−0.419	0.567	−0.302	−0.792
	(0.335)	(0.489)	(0.514)	(0.512)	(0.927)	(0.828)
Fraction of Democrats in state house	0.158	0.839*	0.626	0.528	0.668	0.575
	(0.471)	(0.448)	(0.454)	(0.817)	(1.153)	(0.688)
Unemployment rate	0.0331	0.0117	−0.0141	−0.132*	0.0230	−0.189*
	(0.0382)	(0.0274)	(0.0333)	(0.0659)	(0.127)	(0.101)
Percent state budget surplus	−0.103	−0.131	0.168	0.165	−0.283	0.315
	(0.204)	(0.261)	(0.294)	(0.456)	(0.381)	(0.289)
Average senate LCV rating				0.000423	−0.00129	−0.00298
				(0.00232)	(0.00200)	(0.00205)
Average house LCV rating				0.00769*	0.00136	0.00281
				(0.00398)	(0.00233)	(0.00343)
Manufacturing share of GSP				0.494	1.290	1.952
				(3.250)	(3.042)	(3.384)
Mining share of GSP				−7.144	6.666*	2.925
				(9.131)	(3.355)	(3.638)
Observations	1,607	1,653	1,608	923	969	969
R^2	0.214	0.221	0.221	0.179	0.193	0.201
p-value on F-test of joint-significance	0.13	0.15	0.17	0.31	0.45	0.19

Notes: Standard errors clustered at the state level. All specifications include year fixed effects.
***Significant at the 1 percent level.
**Significant at the 5 percent level.
*Significant at the 10 percent level.

Finally, states that index taxes to the wholesale or retail gas price pose a concern because demand factors such as economic activity may affect wholesale or retail prices, which in turn affect taxes. However, omitting states and years with variable tax rates causes a slight increase in the estimated tax coefficient, suggesting that indexing is not driving our results.

Instrumenting for the Tax-Exclusive Price and Additional Tests.—Next, we turn to the exogeneity of the tax-exclusive price. The tax-exclusive gasoline price may not be exogenous to gasoline consumption if state-level demand or supply shocks are correlated with equilibrium prices and consumption. Including state GSP controls for demand shocks to some extent, but there may be other variables, such as supply-side shocks, that are correlated with both prices and consumption. We use crude oil prices to instrument and correct for the potential endogeneity of the tax-exclusive price. We construct two instruments: (i) the interaction of the tax-exclusive price in 1966 with the average annual price of imported crude oil, and (ii) 1 plus the gasoline tax divided by the annual average price of imported crude oil.[14] In performing the IV regressions, we drop data in 1966 and 1967 and use data from 1968–2008. The interaction of the tax-exclusive price in 1966 with the average annual price of imported crude oil is used to capture how time-invariant, presample conditions (e.g., market structure in wholesale and retail gasoline markets, differences in land and labor costs, distance to refineries) in each state interact with national average crude oil prices to influence state-level tax-exclusive gasoline prices.[15] The validity of this instrument rests on two assumptions. First, the demand shocks after 1967 are not correlated with demand or supply shocks in 1966. To the extent that the demand shocks are serially correlated, this assumption may be violated, but we drop observations in 1967 to alleviate this concern. In other regressions, we further restrict our sample to later years and obtain qualitatively similar results, which supports the validity of the instruments. The second assumption is that state-level demand shocks are not correlated with national average imported crude oil prices. Crude oil prices are set in the international market and demand shocks in a particular state (i.e., deviations from the state average and trend) in the United States are unlikely to affect world oil prices.

We present the IV results in panel A of Table 4. The first three columns replicate columns 6, 8, and 10 in Table 2 using the slightly shorter sample for which our instruments are available (1968–2008). The next three columns present the IV results for the same specifications. After instrumenting, the point estimate for the coefficient on the log of the tax-exclusive price falls in magnitude, while the point estimate for the coefficient on $\ln(1 + taxratio)$ rises slightly in magnitude. In all six specifications, the coefficient on $\ln(1 + taxratio)$ is significantly greater than the coefficient on the log of the tax-exclusive gasoline price (p-values are provided in the table). Panels B and C in Table 4 report the implied percent changes in gasoline consumption from a \$0.05 per gallon increase in the tax-inclusive gasoline price or tax. In all regressions, including the preferred specification in columns 3 and 6, the estimated impacts from a change in gasoline taxes are much larger than those from

[14] We use the average price of imported crude oil rather than the more commonly used WTI or Brent crude spot price because the imported price series begins in 1968. Between 1985 and 2008, during which we observe all three series, the correlation coefficient between the imported crude oil price and the WTI and Brent crude oil spot prices is 0.9988 and 0.9989, respectively.

[15] Muehlegger (2004); Hastings (2004); Hastings and Gilbert (2005); Brown et al. (2008) examine the effects on gasoline prices of market structure, in particular vertical relationships, and environmental regulations from the 1990 Clean Air Act Amendments.

Table 4—IV Estimates of Gasoline Demand

	Uninstrumented (1968–2008)			Instrumented (1968–2008)		
Variables	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Coefficient estimates						
log (tax-excl. gas price)	−0.214***	−0.161**	−0.122**	−0.104***	−0.136***	−0.0697**
	(0.0598)	(0.0494)	(0.0382)	(0.0199)	(0.0194)	(0.0240)
log $(1 + \text{tax ratio})$	−0.732***	−0.469***	−0.290**	−0.795***	−0.501***	−0.323***
	(0.175)	(0.0898)	(0.0895)	(0.179)	(0.0913)	(0.0828)
p-value: $\alpha = \beta$	< 0.001	< 0.001	0.024	< 0.001	< 0.001	0.002
Panel B. Percent changes in gas consumption from a \$0.05/gallon increase in gas price						
Gas price	−0.606***	−0.470***	−0.319***	−0.844***	−0.320***	−0.148*
	(0.171)	(0.144)	(0.111)	(0.254)	(0.063)	(0.076)
Panel C. Percent changes in gas consumption from a \$0.05/gallon increase in gas tax						
Gas tax	−2.163***	−1.385***	−0.856***	−2.350***	−1.479***	−0.955***
	(0.518)	(0.265)	(0.143)	(0.529)	(0.270)	(0.245)
p-value: equal effects	0.004	0.002	0.003	0.010	< 0.001	0.002
State FE	X	X	X	X	X	X
Year FE	X	X	X	X	X	X
Covariates		X	X		X	X
State quadratic trends			X			X

Notes: The dependent variable is the log of gasoline consumption per adult. The standard errors (in parentheses) are clustered by state. All specifications include year and state fixed effects. The log of the oil price interacted with the tax-exclusive gasoline price in 1966 and 1 + gasoline tax/oil price instrument for the tax-exclusive gasoline price and 1 + tax ratio. Covariates are identical to those in Table 2 and include average family size, log road miles per adult, log number of registered cars per capita and log number of registered trucks per capita, log number of licensed drivers per capita, log real income per capita, fraction of the population living in metro areas, and fraction of population living in metro areas with rail transport. Panels B and C report estimated percent changes in gasoline consumption from a \$0.05/gallon increase from either overall gasoline price or gasoline tax corresponding to each specification. The estimates use the average tax and tax-exclusive gas price in 1988 (24.1 cpg and 69.2 cpg), inflated to 2008 US dollars, the last year of our sample.

***Significant at the 1 percent level.
**Significant at the 5 percent level.
*Significant at the 10 percent level.

an equivalent change in the tax-inclusive gasoline prices (which are obtained from a regression that does not decompose the tax-inclusive price).

To further investigate this issue, we conduct two analyses to examine the effects of omitted variables that may be correlated with state tax rates, tax-exclusive gasoline prices, and gasoline consumption, and which may consequently drive a spurious difference between the estimated effects of the tax rate and tax-exclusive gasoline prices. Of particular concern are unobserved trending variables, e.g., omitted demographic trends affecting vehicle ownership or driving intensity that are correlated with the state gasoline tax.

First, we examine a shorter state-level panel where we have available *monthly* gasoline taxes, prices, and consumption from 1983 to 2008. We estimate a first-differenced version of (2) using the monthly data. First-differencing the higher frequency data makes it less likely that omitted variables bias the coefficients because an omitted variable must change in the same month as the state excise tax to bias the coefficients. We present the results in Table 5. As a point of comparison,

Table 5—Gasoline Taxes, Tax-Exclusive Prices, and Consumption, Monthly

	Levels		First-differenced		First-differenced seasonal data	
Variable	(1)	(2)	(3)	(4)	(5)	(6)
log (gas price)	−0.196***		−0.248***		−0.109*	
	(0.030)		(0.030)		(0.057)	
log (tax-excl. gas price)		−0.217***		−0.365***		−0.172***
		(0.028)		(0.047)		(0.061)
log (1 + tax ratio)		−0.414***		−0.769***		−0.394***
		(0.046)		(0.157)		(0.140)
p-value: $\alpha = \beta$		< 0.001		< 0.001		0.038
Observations	14,898	14,898	14,763	14,763	4,893	4,893
R^2	0.987	0.987	0.446	0.446	0.466	0.467

Notes: The dependent variable is the log of gasoline consumption per adult. All specifications include time fixed effects. Levels regressions also include state fixed effects. Robust standard errors are clustered by state.
***Significant at the 1 percent level.
**Significant at the 5 percent level.
*Significant at the 10 percent level.

columns 1 and 2 recreate the earlier levels regressions from Table 2 using the shorter monthly panel.[16] The estimated coefficients from the regressions in levels are similar to the earlier estimates using the longer, annual panel. Columns 3 and 4 regress gasoline consumption on the tax-exclusive price and tax rate, after first-differencing. As in the levels regression, we find a significant difference between the coefficients on the tax-exclusive price and the tax rate.

One drawback to using first-differenced monthly data is the possibility that consumers shift consumption in response to anticipated changes in gasoline prices or taxes. In this case, first-differenced gasoline consumption may appear to be more responsive than in our levels regressions. As an additional check, we aggregate the data by season, year, and state before first-differencing in columns 5 and 6. At the seasonal level, intertemporal substitution is unlikely to be a problem. Although the size of both coefficients declines, we continue to find a statistically significant difference between the coefficients on the tax-exclusive price and the tax rate. This suggests that the results in columns 3 and 4 are not being driven entirely by the strategic timing of gasoline purchases around tax changes.

Figure 6 presents further evidence that omitted variables do not bias the estimates. Trends existing prior to gasoline tax changes would suggest the presence of omitted variables bias. The figure plots changes in gasoline consumption over time prior to and following an increase in the gasoline tax that occurs between period −1 and period 0. Specifically, we replace the tax variable in equation (2) with two series of indicator variables. The first series includes variables equal to 1 if the state tax increased four years earlier, three years earlier, and so on, up to a variable equal to 1 if the state tax increases four years in the future; the second series includes corresponding indicator variables for tax decreases. The figure plots the coefficients

[16] When regressing in levels, we include state fixed effects and time fixed effects. In the first-differenced specification, we only include time fixed effects.

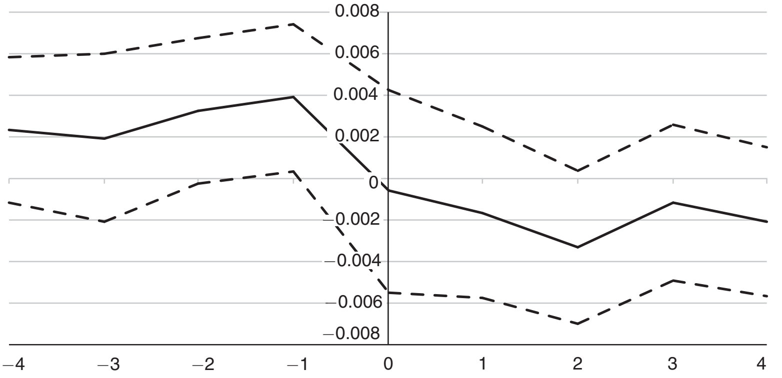

Figure 6. Change in Gas Consumption, Pre- and Post-Tax Change

on the increase indicator variables, along with the 95 percent confidence intervals. The figure shows no evidence of a downward trend in gasoline consumption prior to tax increases. There is a sudden and persistent decrease in gasoline consumption in the year of the tax increase. Thus, there is no evidence of a preexisting trend. We do not report the coefficients on the tax decrease variables because there are very few tax decreases in the data.

Finally, we consider the dynamics in the effect of taxes and tax-exclusive prices on gasoline consumption. The specifications in Table 2 assume a log-linear and contemporaneous relationship between the dependent variables and the tax and tax-exclusive price. In the following, we examine potential asymmetric and lagged responses to price changes. There is some evidence in the literature that consumers respond more to gasoline price increases than to decreases. Because there are so few examples of tax decreases in the data (about one per state on average), it is not possible to assess statistically whether there is a differential tax response. It is possible to investigate asymmetric responses to tax-exclusive prices, however, by adding to the main specification the interaction of the tax-exclusive price with a dummy equal to 1 if the price increased between the previous and current years. If consumers respond more to a price increase than to a decrease, the coefficient would be negative, but in fact the coefficient is positive and statistically significant. The coefficient is quite small, however, and we do not find an economically meaningful difference in the response to tax-exclusive price increases.

Regressions in Table 6 investigate lagged responses by including lags of the tax-exclusive price and the tax. The results show that adding three lags of both variables reduces the point estimates on the current tax and tax-exclusive variables. The coefficients on the lags are larger than the coefficients on the current tax or tax-exclusive price, and are more precisely estimated. The hypothesis is rejected at the 5 percent level that the sum of the current and lagged tax-exclusive coefficients equal those for the gasoline tax variable; the differential effect of gasoline taxes and tax-exclusive prices still exist. Even if we allow for lagged responses to taxes and tax-inclusive prices, we find a larger response to taxes than tax-inclusive prices. This suggests that a differential effect could exist even in the long-run responses to gasoline taxes and tax-exclusive prices.

Table 6—Coefficient Estimates: Lagged Prices and Taxes

Variable	Specification: Total gas price (1)	Specification: Separate tax from tax-excl. price (2)
log (gas price)	−0.066*	
	(0.034)	
1-year lag gas price	−0.019	
	(0.024)	
2-year lag gas price	−0.037*	
	(0.019)	
3-year lag gas price	−0.066**	
	(0.029)	
log (tax-excl. gas price)		−0.060
		(0.036)
1-year lag tax-excl. gas price		−0.029
		(0.027)
2-year lag tax-excl. gas price		−0.037
		(0.022)
3-year lag tax-excl. gas price		−0.065**
		(0.031)
log (1 + tax ratio)		−0.084
		(0.078)
1-year lag log (1 + tax ratio)		−0.117*
		(0.064)
2-year lag log (1 + tax ratio)		−0.106*
		(0.056)
3-year lag log (1 + tax ratio)		−0.157**
		(0.072)

Notes: The dependent variable is the log of gasoline consumption per adult. Specifications are the same as in columns 5 and 6 of Table 2, except that 1-, 2-, and 3-year lag of the gas price and tax variables are added.

E. *Explanations*

Persistence.—One possible explanation for the larger response to gasoline taxes than gasoline prices lies in the fact that the durable goods nature of automobiles implies that consumers' responses depend on their expectations of future fuel costs. If consumers consider tax changes to be more persistent than gasoline price changes due to other factors, a larger response to gasoline taxes than prices could arise through vehicle choice in both the short and long run. Although the short-run response of VMT to gasoline price changes is unlikely to depend on the persistence of price changes, the longer-run response to persistent changes could be greater than to temporary changes because of transaction costs involved in travel mode and intensity decisions (such as setting up carpooling or changing where to live and work).

A formal test of this explanation is out of scope of this study. Nevertheless, in the following, we provide some suggestive evidence for its plausibility.

To examine the persistence of gasoline taxes and gasoline prices, we conduct AR(1) regressions with these two variables using the state-level panel data and controlling for state and year fixed effects. Using the dynamic panel data approach in

Blundell and Bond (1998), we obtain an AR(1) coefficient of 0.925 with a robust standard error of 0.018 for gasoline taxes and 0.822 with a robust standard error of 0.018 for (tax-inclusive) gasoline prices.[17] This suggests that gasoline tax changes are more persistent even after including state and year fixed effects; of course, consumer perceptions of persistence could be different from these estimates, which we discuss further below. Nevertheless, to examine what the difference implies for fuel costs, we calculate the increase in the total *expected* discounted fuel costs during a vehicle's lifetime from a \$0.05 increase in the current period of (i) the gasoline tax and (ii) the tax-exclusive gasoline price. For an average car that achieves 25 MPG, assuming that the VMT schedule during the lifetime decreases as in Lu (2007), and assuming a 5 percent annual discount rate, the increase in the total expected discounted fuel costs is \$163 for a tax increase compared with \$111 for an equal gasoline price increase. For an average light truck that achieves 18 MPG, the increases in the total expected discounted fuel costs are \$248 and \$167, respectively. The larger difference for light trucks is due to the lower fuel economy as well as the larger lifetime VMT for light trucks.

Based on survey data from 1993 to 2009 from the Michigan Survey of Consumers, Anderson, Kellogg, and Sallee (2012) find that, on average, consumers assume that the expected future prices equals the current price. We argue that this finding does not dismiss the persistence explanation for the following three reasons. First, their analysis is on overall gasoline prices and their finding does not rule out differential consumer beliefs for the two price components—more specifically, differential consumer beliefs about within-year deviations from state averages and trends, which are the basis for our identification. Second, they document considerable cross-sectional heterogeneity in consumer beliefs. The degree of heterogeneity increases with gasoline prices, which suggests that some consumers do not expect gasoline price changes (and possibly tax-exclusive price changes) to be fully persistent. Third, they find that the characteristics of consumer beliefs differ over time. For example, they deviate substantially from a no-change forecast after the financial crisis hit in 2008. Our data period is from 1966 to 2008 and includes several episodes of economic downturns and volatile gasoline prices.

Salience.—A second possible explanation is that gasoline tax changes may be more salient to consumers than changes in the tax-exclusive price. A number of recent empirical studies demonstrate that consumer are more responsive to salient price and tax changes (Busse, Silva-Risso, and Zettelmeyer 2006; Chetty, Looney, and Kroft 2009; and Finkelstein 2009). Although the salience of gasoline taxes and pre-tax price changes may differ for a number of reasons, we focus on news coverage and examine whether tax increases receive more media attention than commensurate increases in the tax-exclusive price of gasoline. If news coverage informs consumers of price and tax changes, consumers may respond more to changes that are heavily covered in the news media than changes that are not. Thus, our mechanism is similar

[17] A coefficient estimate of 0.775 is obtained for tax-exclusive gasoline prices following the same method. Adding the instrument based on crude oil prices as constructed above for both tax-inclusive and tax-exclusive gasp prices changes their coefficients to 0.828 and 0.782, respectively.

to Rivers and Schaufele (2012), who argue that the publicity surrounding the carbon tax in British Columbia may explain the large consumer response to the tax.

To test whether gasoline taxes receive disproportionate levels of media attention, we collect data on the coverage of gasoline-related topics in major US newspapers and on nightly television news broadcasts. Our data on print media come from LexisNexis and include the 15,623 unique articles indexed by LexisNexis as being highly relevant to either gasoline prices or gasoline taxes published in 25 major US newspapers from 1985 to 2008.[18] The newspapers include both national dailies (e.g., *The New York Times* and *USA Today*) and major regional newspapers (e.g., *The Denver Post*, *Detroit News*, and *Minneapolis Star Tribune*).[19] For each article, we observe the date it was published and article word count. To construct our measures of print media coverage, we sum the word count of all articles classified by LexisNexis as highly relevant to "gasoline prices" and "fuel taxes" in each month.

Our data on nightly television news broadcasts are drawn from the Vanderbilt Television News Archive. Our dataset covers 1983–2010 and includes information on all 3,926 ABC, NBC, CBS, FOX, and CNN nightly news segments for which the word "gasoline" appeared in the abstract of the segment. In addition to the abstract, the archive provides the date, network, and length of the segment.[20] Our measure of television media coverage is the total number of seconds of coverage of gasoline segments for which the words "price" or "tax" appear in the detailed abstract in each month. As an example, the segment cited in footnote 20 would be classified as a segment related to gasoline prices, but not a segment related to gasoline taxes.

Our empirical approach and basic results can be summarized in a pair of graphs. Figures 7 and 8 graph the word count over time, of gasoline-related articles in print media and the total seconds of gasoline-related nightly news coverage. The solid vertical lines correspond to federal gas tax increases in 1990 (5.1 cpg) and 1993 (4.3 cpg) and the May 1996 congressional debate over repealing the 1993 gas tax increase. The dashed lines correspond to the months in which tax-exclusive prices increased by similar amounts. Both print media and nightly news coverage increase much more prior to actual or proposed changes in the federal tax than to comparable changes in the tax-exclusive price. Some gas price changes do trigger substantial media coverage, but those price changes are much larger than the tax changes. Using print media as an example, gasoline-related coverage in major US papers at the time

[18] LexisNexis scans the content of all documents in its repository using a set of internally developed, predefined classifications rules. For each index term (e.g., gasoline prices or gasoline taxes), LexisNexis calculates a relevancy score based on the frequency and location of phrases in the article related to the term. We use articles classified by LexisNexis as being "highly relevant" to either gasoline prices or gasoline taxes.

[19] The comprehensive list of newspapers is: *Los Angeles Times*, *Minneapolis Star Tribune*, *Newsday*, *Pittsburgh Post-Gazette*, *St. Louis Post-Dispatch*, *Tampa Bay Times*, *The Atlanta Journal-Constitution*, *The Baltimore Sun*, *The Buffalo News*, *The Daily Oklahoman*, *The Denver Post*, *The Detroit News*, *The Hartford Courant*, *The New York Daily News*, *The New York Post*, *The New York Times*, *The Orange County Register*, *The Philadelphia Daily News*, *The Philadelphia Inquirer*, *The Tampa Tribune*, *The Washington Post*, and *USA Today*. Although LexisNexis includes the *Journal of Commerce* and the *Christian Science Monitor* as "Major US Newspapers," we exclude the publications from our analysis as both are substantially different from daily newspapers.

[20] As an example, *ABC Nightly News* aired a 90-second segment on May 22, 2013, with the abstract "(Studio: Diane Sawyer) AAA predictions for the number of drivers out on Memorial Day cited. (New York: Rebecca Jarvis) The continuing rise in gasoline prices examined; gas price statistics cited. [GasBuddy.com oil industry analyst Tom Kloza—says the prices are linked to refinery work in the middle of the country.] Some money-saving driving tips outlined on screen."

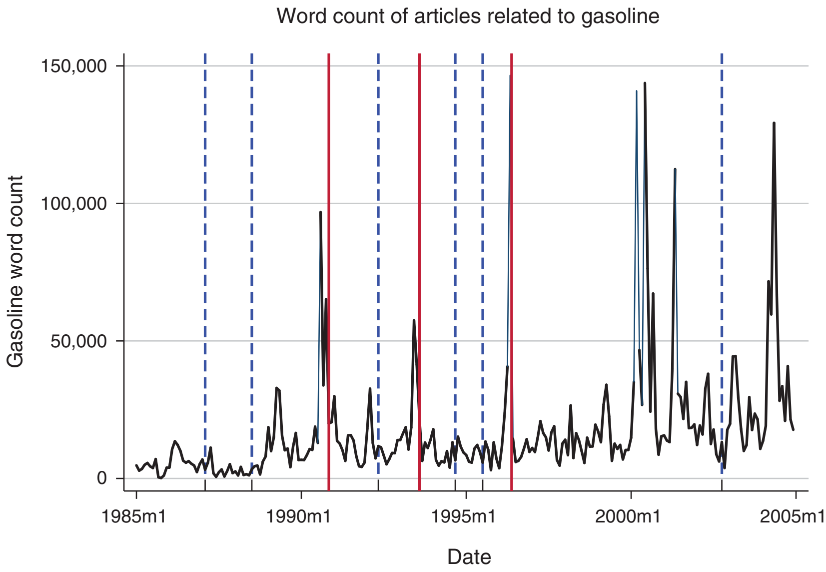

Figure 7. Print Media Coverage, Gasoline Price, and Tax Changes

Notes: The y-axis measures monthly total word count of articles in major US newspapers classified by LexisNexis as highly relevant to gasoline prices or taxes. Solid vertical lines represent dates of (i) the December 1990 federal gas tax change (5.1 cpg), (ii) the October 1993 federal gas tax change (4.3 cpg), and (iii) the May 1996 debate over repealing the 1993 gas tax. Dashed vertical lines represent months with comparable tax-exclusive price increases.

of the two tax changes and the 1996 gas tax debate was between 50,000 and 150,000 words per month. Tax-exclusive price changes that triggered similar amounts of media coverage were at least six times larger than the actual federal tax changes. It is important to note we estimate equation (2) with year fixed effects that subsume the three national tax events and identify the effects of gasoline taxes solely from changes in state tax rates. Unfortunately, the Vanderbilt television archive only provides information about national news broadcasts and thus, we are not able to examine state television media coverage of the state tax changes alone.[21] Nonetheless, the media analysis for federal taxes provides insights into the salience of state taxes.

To test formally whether taxes receive disproportionate media coverage, we regress print and television media coverage on the change in *tax-inclusive* gasoline prices and per gallon gasoline taxes in the previous three months and upcoming three months. Our specification is:

$$(3) \qquad MediaCoverage_t = \alpha + \beta_1 \times \Delta p_{t,t-3} + \beta_2 \times \Delta p_{t+3,t} + \gamma_1 \times \Delta \tau_{t,t-3} + \gamma_2 \times \Delta \tau_{t+3,t} + f(t) + \epsilon_t ,$$

[21] We are able to examine state print media coverage of all articles related to gasoline and find that, before taxes rise, both state and federal gasoline taxes receive coverage of similar magnitude. Furthermore, the coverage is significantly greater than that received by commensurate changes in the price of gasoline.

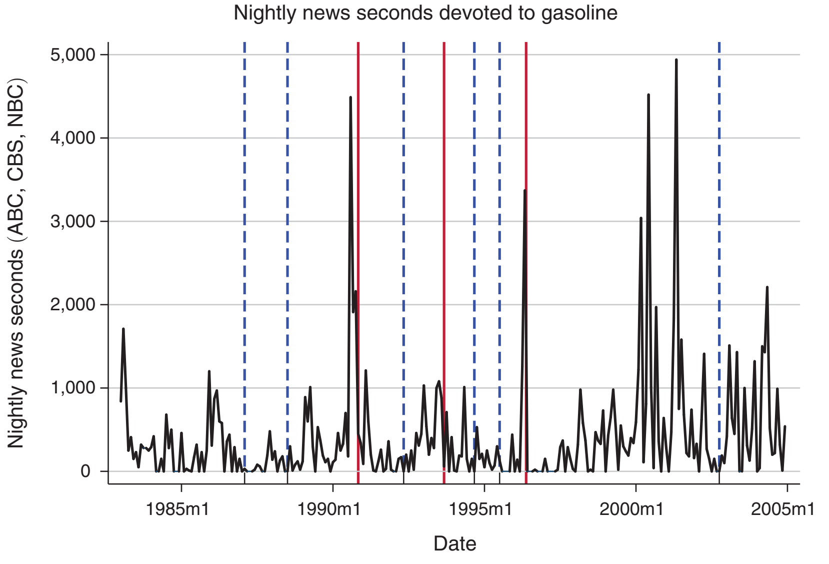

Figure 8. Nightly News Coverage, Gasoline Price, and Tax Changes

Notes: The y-axis measures monthly seconds of gasoline-related nightly news coverage on ABC, CBS, and NBC. Solid vertical lines represent dates of (i) the December 1990 federal gas tax change (5.1 cpg), (ii) the October 1993 federal gas tax change (4.3 cpg), and (iii) the May 1996 debate over repealing the 1993 gas tax. Dashed vertical lines represent months with comparable tax-exclusive price increases.

where $\Delta p_{t,t-3}$ and $\Delta \tau_{t,t-3}$ are the changes in the average *tax-inclusive* price and average per gallon tax over the previous three months, $\Delta p_{t+3,t}$ and $\Delta \tau_{t+3,t}$ are the changes in the upcoming three months, and $f(t)$ denote a set of time effects.[22] Marion and Muehlegger (2011) find strong evidence of full and immediate pass-through of gasoline taxes to retail prices. Consequently, we interpret the coefficients γ_1 and γ_2 as the amount of *additional* news coverage following and preceding a change in gasoline taxes above what would be expected for a commensurate change in the tax-exclusive price.

Table 7 reports the estimates from the regression.[23] The four columns for print and nightly news coverage correspond to specifications using different dependent variables. From left to right, the columns report the results using as dependent variables the coverage related to gasoline prices, gasoline taxes, gasoline price or taxes, and the log of coverage of gasoline prices or taxes. Focusing on any coverage related to gasoline, we estimate that a \$0.01 change in retail prices over the preceding three months is associated with 805 words of newspaper coverage and 14 seconds of additional nightly news coverage. A \$0.01 change in gasoline taxes over the preceding

[22] For print media coverage, we include a quadratic time trend to capture the gradual addition of newspapers tracked by LexisNexis. For television media coverage, we include dummy variables for portions of the study period during which the Vanderbilt Television News Archive transcribed FOX and CNN news broadcasts in addition to ABC, CBS, and NBC broadcasts. In all specifications, we also include a dummy for the month of May 1996, during which congress debated repealing the 1993 federal gasoline tax increase.

[23] We also perform regressions using log(gas tax) and log(1 + tax ratio) as explanatory variables and obtain the same qualitative findings.

TABLE 7—MEDIA COVERAGE, GASOLINE PRICE, AND TAX CHANGES

	Print media coverage: Word count				Nightly news coverage: Seconds			
	Gas prices	Gas taxes	All gas	log (all gas)	Gas prices	Gas taxes	All gas	log (all gas)
Change in gas price previous three months	748.7***	97.94***	805.9***	0.0123***	11.80***	1.899**	14.05***	0.00740**
	(161.4)	(34.55)	(173.8)	(0.00279)	(3.888)	(0.840)	(4.501)	(0.00327)
Change in gas tax previous three months	2,833.3***	377.2	2,869.8***	0.177***	3.330	0.353	18.42	0.193**
	(914.0)	(278.3)	(1,025.0)	(0.0383)	(15.92)	(7.804)	(34.06)	(0.0898)
Change in gas price next three months	−291.8***	17.85	−271.0***	−0.00486***	−10.32***	0.0455	−11.80***	−0.0113***
	(73.23)	(12.44)	(72.56)	(0.00102)	(2.737)	(0.785)	(3.539)	(0.00282)
Change in gas tax next three months	1,432.9**	2,163.2*	3,621.5***	0.275***	49.22	73.92**	129.0**	0.392***
	(684.3)	(1,193.8)	(1,372.1)	(0.0567)	(36.56)	(36.37)	(58.61)	(0.0979)
May 1996 gas tax repeal debate	52,682.8***	67,826.7***	102,400.1***	2.301***	2,536.6***	3,767.1***	3,029.6***	2.940***
	(3,184.5)	(816.4)	(3,412.9)	(0.0827)	(119.5)	(32.17)	(138.2)	(0.204)
Constant	8,423.6***	2,504.7***	10,898.5***	8.169***	109.7***	40.93***	239.2***	4.398***
	(2,438.7)	(829.3)	(2,757.0)	(0.196)	(36.16)	(13.77)	(43.54)	(0.153)
Observations	282	282	282	282	330	330	330	330
R^2	0.574	0.383	0.567	0.537	0.267	0.256	0.423	0.153

Notes: Columns 1–4 include a quadratic time trend. Columns 5–8 include fixed effects corresponding to the period of time CNN and FOX transcripts are included in the Vanderbilt Television News Archive. Robust standard errors are reported in parentheses.

three months is associated with 2,870 words of additional coverage. Moreover, a \$0.01 change in taxes over the subsequent three months is associated with 3,621 words of additional coverage and 129 seconds of additional network airtime. Taken in aggregate before and after a change, a \$0.01 tax change is associated with an order of magnitude greater increase in media coverage, as compared to a \$0.01 change in the tax-exclusive price.

III. Household Data Analysis

Vehicle purchase and driving constitute the extensive and intensive margins through which the gasoline price affects gasoline demand.[24] The purpose of this section is to further examine how the gasoline tax and tax-exclusive gasoline prices affect the two margins. We conduct analysis on household vehicle purchase and travel using the 1995, 2001, and 2009 National Household Travel 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.

A. *Empirical Methodology*

We employ a similar empirical strategy to the one used to examine the aggregate data, but exploit the richer set of demographics and geographic characteristics present in the household-level data. For the vehicle fuel economy analysis, we focus on households who purchased at least one vehicle (new or used) during the past

[24] Vehicle scrappage is part of the extensive margin but is not examined in this paper due to data limitations.

12 months. In the survey, the purchase time (year and month) is available for the recently purchased vehicles. For these households, it is possible to match the vehicle MPG and the gasoline price in the purchase month and the preceding months. We estimate the following equation to examine how gasoline prices affect vehicle purchases:

$$\ln(MPG_{it}) = \alpha_m \ln(p_{sq}) + \beta_m \ln\left(1 + \frac{\tau_{sq}}{p_{sq}}\right) + X_i\Theta_m + \delta_s + \phi_t + e_i, \tag{4}$$

where i denotes a household surveyed in month t, s denotes the state, and q denotes a quarter. MPG_{it} is the average MPG of all the new and used vehicles (cars and light trucks) purchased during the past 12 months by household i surveyed in month t. The key explanatory variables include the tax-exclusive gasoline price and the tax ratio. Importantly, the tax and price correspond to the household's state and the quarter of purchase. We include a large set of household demographics. We use quadratic functions for the noncategorical variables: household size, the age of the reference person, the number of adults, the number of workers, and the number of drivers in each household. We include full sets of fixed effects for the categorical variables: household income, education of the reference person, MSA size, worker density by census tract, population density by census tract, rail availability, and urban and rural indicator variables. We also include fixed effects for year, month, and location (census division or state).

To examine the effect of the tax-exclusive gasoline price and the gasoline tax on household travel behavior, we estimate the following equation:

$$\ln(VMT_{it}) = \alpha_v \ln(p_{sq}) + \beta_v \ln\left(1 + \frac{\tau_{sq}}{p_{sq}}\right) + X_i\Theta_v + \delta_s + \phi_t + e_i, \tag{5}$$

where VMT_{it} is the daily total VMT across all vehicles belonging to household i that was surveyed in month t. The VMT equation includes the same set of variables as the MPG equation with the exception of month fixed effects, which are constructed to match the travel period.

B. *Sources*

Household data from the NHTS provide detailed demographic characteristics about each household. Each household is assigned to 1 of 18 income bins and 8 education bins. The data include the number and age of adults and the numbers of 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, housing density, and the availability of rail. Consequently, the NHTS data provide a detailed set of controls for characteristics that may vary with both a state's tax rate and the household's driving or purchase decisions.

For the MPG analysis, we use the 1995, 2001, and 2009 NHTS. The data include the make and model of the household's vehicles, which we match to the EPA fuel

Table 8—Summary Statistics: MPG of Recently Purchased Vehicle

	Sample 1. All purchases				Sample 2. Newer vehicles			
Variable	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.
Average MPG	21.44	5.17	10.00	49.80	21.40	5.30	10.12	49.25
Tax-excl. gas price	1.64	0.76	0.70	3.94	1.60	0.75	0.70	3.94
Gas tax	0.42	0.07	0.24	0.69	0.42	0.07	0.24	0.69
Household size	2.97	1.43	1	14	2.82	1.35	1	14
Number of drivers	2.11	0.83	0	10	2.06	0.76	0	10
Number of adults	2.12	0.79	1	10	2.07	0.73	1	10
Number of workers	1.59	0.94	0	10	1.55	0.90	0	10
Age of reference person	45.37	14.53	17	92	46.99	14.64	17	92
Household income	10.71	5.21	1	18	12.10	4.93	1	18
Education of ref. person	3.03	1.13	1	5	3.23	1.11	1	5
MSA size	4.13	1.45	1	6	4.16	1.39	1	6
Worker density	1,192	1,442	25	5,000	1,227	1,436	25	5,000
Population density	3,596	4,912	50	30,000	3,636	4,747	50	30,000
With rail	0.21	0.41	0	1	0.24	0.43	0	1
Without rail	0.79	0.41	0	1	0.76	0.43	0	1
Second city	0.19	0.39	0	1	0.18	0.38	0	1
Suburban	0.27	0.45	0	1	0.31	0.46	0	1
Town and country	0.42	0.49	0	1	0.39	0.49	0	1
Urban	0.12	0.33	0	1	0.12	0.33	0	1

Notes: Sample 1, with 52,128 observations, includes households who purchased at least one vehicle within the past year, from the 1995, 2001, and 2009 NHTS. Sample 2, with 30,363 observations, includes households who purchased at least one vehicle during the past year such that all the vehicles purchased are less than four years old. Tax-exclusive gasoline price and gasoline tax correspond to the purchase month (and are averaged in case of multiple vehicle purchases). Household income, education of reference person, MSA size, worker density, and population density at the census tract level are all categorical variables.

economy database to obtain MPG for each vehicle. Gasoline prices at the time of purchase are based on the gasoline prices used in the aggregate analysis. Because purchases of newer vehicles may respond more to price changes than purchases of older vehicles, our analysis is conducted on two separate samples. The first sample, with 52,128 observations, includes households that purchased at least one used or new vehicle during the 12 months prior to the survey. The second sample focuses on newer vehicles. It has 30,363 households who purchased at least one vehicle during the past 12 months and all the vehicles purchased are less than four years old. Table 8 provides summary statistics for the two samples. The average MPG of vehicles in the two samples is almost the same and other variables are quite close as well. The households in sample 2 (those who purchased newer vehicles) have slightly smaller household size, higher income, and more education.

We use a subset of the NHTS data to examine VMT. During the 1995 and 2001 surveys, participants received an initial survey followed by a second survey several months later. In both, participants were asked to report odometer readings of all of their vehicles. 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 the odometer readings 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 that have missing data for either

Table 9—Summary Statistics: Household VMT

	Sample 1. Odometer readings				Sample 2. Self-reported VMT			
Variable	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.
Average daily VMT	50.82	35.71	0.01	347.96	58.94	50.03	0.00	499.09
Tax-excl. gas price	1.07	0.12	0.74	1.69	1.13	0.13	0.87	1.68
Gas tax	0.46	0.06	0.29	0.71	0.45	0.06	0.29	0.68
Household size	2.33	1.32	1	12	2.51	1.38	1	14
Number of drivers	1.69	0.67	0	6	1.79	0.73	−8	10
Number of adults	1.74	0.66	1	8	1.83	0.71	1	9
Number of workers	1.16	0.88	0	6	1.32	0.91	−8	10
Age of reference person	50.98	16.42	17	88	47.85	16.12	17	88
Household income	9.33	4.96	1	18	9.48	4.96	1	18
Education of reference person	3.09	1.18	1	5	3.02	1.15	1	5
MSA size	4.06	1.40	1	6	4.10	1.42	1	6
Worker density at census tract	1,397	1,507	25	5,000	1,396	1,531	25	5,000
Population density at census tract	4,000	4,907	50	30,000	3,890	4,856	50	30,000
With rail	0.22	0.41	0	1	0.21	0.41	0	1
Without rail	0.78	0.41	0	1	0.79	0.41	0	1
Second city	0.21	0.41	0	1	0.21	0.41	0	1
Suburban	0.32	0.47	0	1	0.29	0.45	0	1
Town and country	0.34	0.47	0	1	0.37	0.48	0	1
Urban	0.13	0.34	0	1	0.13	0.34	0	1

Notes: Sample 1, with 28,303 observations, is from the 1995 and 2001 NHTS and includes households who reported two odometer readings for each of the vehicles owned. Sample 2, with 61,795 observations, includes households with self-reported annual VMT for each vehicle owned. In sample 1, the tax-exclusive gasoline price and gasoline tax are averaged during the period of the two odometer readings. Household income, education of reference person, MSA size, worker density, and population density at the census tract level are all categorical variables.

of the two odometer readings for any of the vehicles owned by the household. The final VMT dataset contains 28,303 observations. Table 9 reports summary statistics under sample 1.

To our knowledge, whereas the previous literature has used self-reported annual VMT, this is the first use of VMT data based on two odometer readings from the NHTS. We compare the results using odometer-based VMT with the results using self-reported annual VMT. The dataset with self-reported annual VMT is larger and contains 61,795 observations. Table 9 reports summary statistics for the self-reported sample under sample 2.

To compare daily VMT based on the two types of VMT estimates, we use 24,528 households with both values. The (weighted) average daily VMT based on odometer readings is 49.9 with a standard deviation of 35.3, while the average self-reported daily VMT is 50.1 with a standard deviation of 45.4. The top graph in Figure 9 plots kernel densities of the two VMT measures; the distributions of the two variables are quite similar. Nevertheless, the comparison of the two distributions masks the differences that exist for a given observation. We find that although the means of the two variables are quite close, the difference between the two measures (for a given household) can be quite large: the mean difference is 0.2 but the standard deviation is 38.5.

To further understand the difference, we compare the two VMT measures for two subsamples that are defined according to whether the odometer-based VMT is above or below the sample mean of 49.9 (which we refer to as high- and low-VMT households). The average daily odometer-based VMT for the two subsamples is

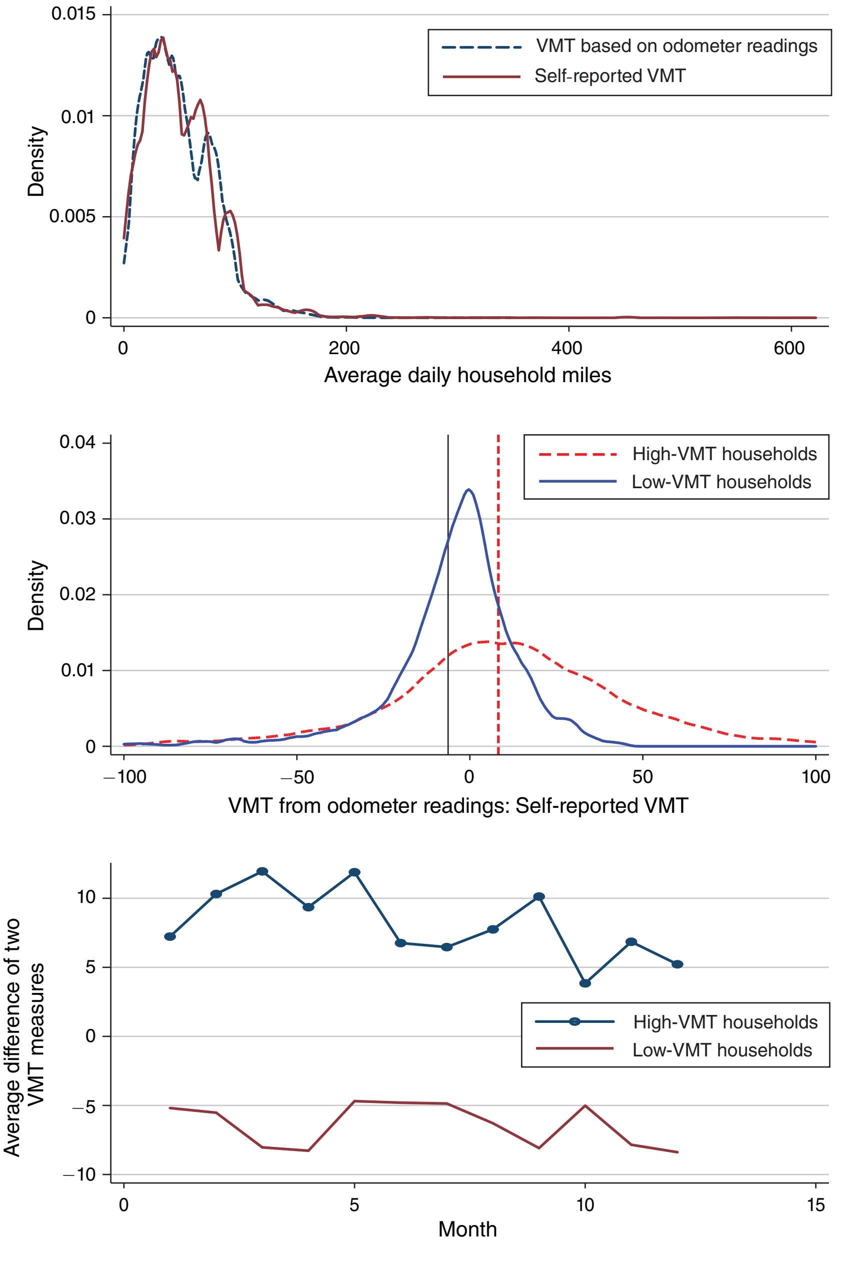

Figure 9. Densities of Daily VMT from Odometer Readings and Self-reported Annual VMT

83.0 and 26.0, while the average self-reported daily VMT is 74.7 and 32.3 for the two subsamples. The middle graph in Figure 9 plots the kernel densities of the difference between the odometer-based and self-reported VMT for the high- and low-VMT subsamples separately, with vertical lines indicating the sample averages. High-VMT households tend to under-report their travel intensity, and low-VMT households tend to over-report.

Table 10—Comparison of NHTS and Estimation Subsample

	Full NHTS sample			Estimation subsample		
	N	Mean	SD	N	Mean	SD
Panel A. Unweighted						
Tax-exclusive price	45,459	0.89	0.12	34,234	0.89	0.12
Tax	41,389	0.40	0.04	34,234	0.40	0.04
Household size	106,831	2.60	1.34	34,234	2.56	1.29
Number of drivers	106,831	1.85	0.77	34,234	1.88	0.70
Number of adults	111,850	1.89	0.82	34,234	1.91	0.65
Number of workers	106,831	1.36	0.96	34,234	1.35	0.94
Age	111,850	49.59	18.79	34,234	50.66	15.67
MSA has subway	111,850	0.16	0.37	34,234	0.14	0.34
Panel B. Weighted						
Tax-exclusive price	45,459	0.87	0.12	34,234	0.89	0.12
Tax	41,389	0.37	0.04	34,234	0.37	0.04
Household size	106,831	2.54	1.34	34,234	2.53	1.35
Number of drivers	106,831	1.85	0.73	34,234	1.84	0.73
Number of adults	111,850	1.89	0.70	34,234	1.88	0.70
Number of workers	106,831	1.30	0.94	34,234	1.31	0.93
Age	111,850	50.25	16.15	34,234	49.76	15.97
MSA has subway	111,850	0.20	0.40	34,234	0.22	0.41

Because two odometer readings could happen any time during the year (and are 2–6 months apart in general), part of the differences could be caused by seasonality in driving. To check if this is driven by seasonality, we compare the two measures month by month and find that the pattern still holds in each of the 12 months (see the bottom graph in Figure 9). To the extent that gasoline prices are negatively correlated with travel, this finding implies that using self-reported VMT in the regression analysis could attenuate the effect of gasoline prices on travel demand.

Because the observations used for our VMT analysis only constitute about one-third of the full sample, it is important to know how representative the estimation sample is. Table 10 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 versus 49.59) and less likely to live in an MSA with a subway system (14 percent versus 16 percent). Overall, however, the mean and the tenth and ninetieth percentiles of the variables are quite similar for the full sample and the estimation sample. Figures 10 and 11 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.[25]

[25] In addition, we preform a logit regression using the self-reported sample in which the dependent variable indicates whether the two odometer readings are missing. Explanatory variables are the same as in equation (5). Most of the demographic variables are not statistically significant although households with higher income are more likely to have missing odometer readings. Importantly, the key explanatory variables, the tax-exclusive gas price and tax, are not statistically significant.

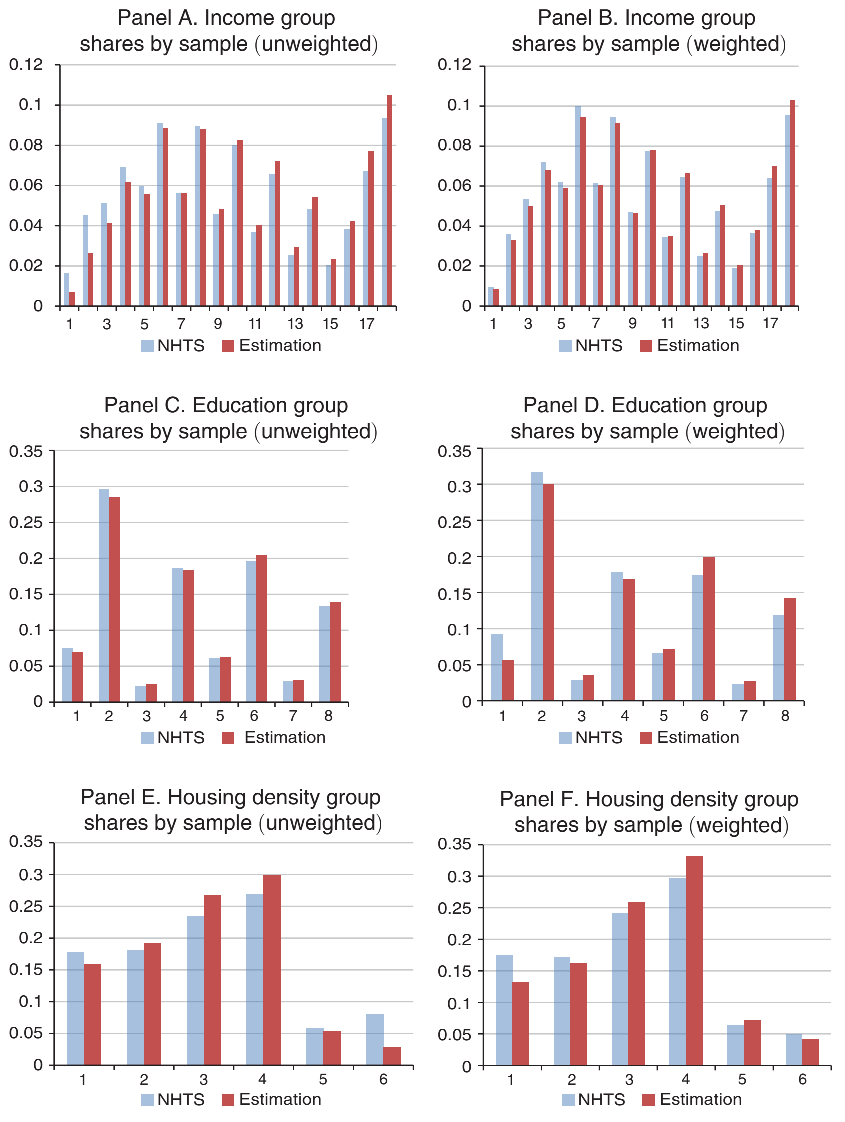

Figure 10. Summary Statistics for NHTS Categorial Variables (*Continued to Figure 11*)

The empirical strategy for gasoline consumption and VMT uses cross-state and time-series variation in the tax-exclusive prices and gasoline taxes. An important concern is that the tax-exclusive prices, taxes, and the dependent variables may be correlated with omitted variables. To investigate this possibility, we examine whether gasoline taxes and tax-exclusive prices are correlated with the independent variables. In particular, we separate states according to whether they have high gasoline taxes or tax-exclusive prices. Across the samples, we compare the means and the tenth and ninetieth percentiles of the independent variables. In general, we find that the distributions are quite similar, which is consistent with the assumed exogeneity of tax-exclusive prices and taxes.

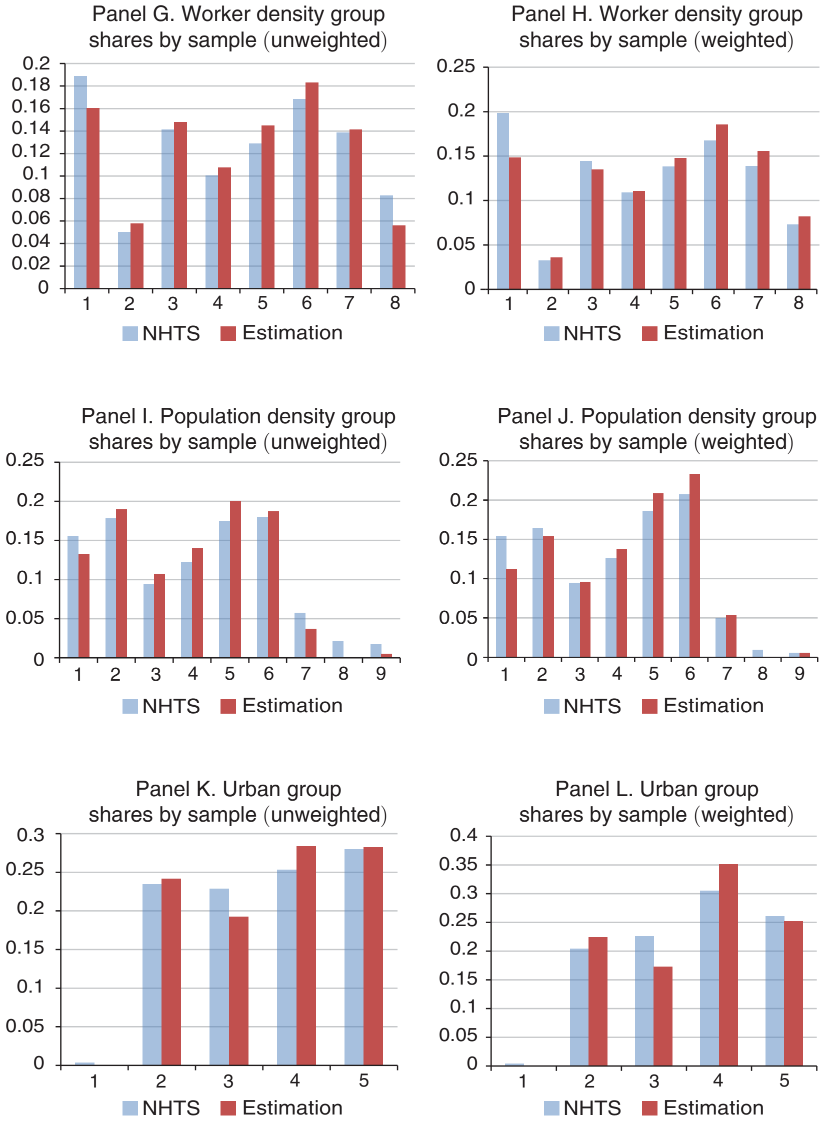

Figure 11. Summary Statistics for NHTS Categorial Variables (*Continued from Figure 10*)

C. *Results*

Table 11 reports key parameter estimates for 12 regressions, examining how gasoline prices and taxes affect the fuel economy of recently purchased vehicles. The table also provides implied percent changes in gasoline consumption from a $0.05 per gallon increase in the gasoline price or tax. Panel A shows six regressions of the effect of the tax-inclusive gasoline price on the average MPG of recently purchased vehicles. Columns 1–3 use sample 1 (all households), and columns 4–6 use sample 2 (households purchasing vehicles less than four years old).

Columns 1–3 of Table 11 differ according to whether census division dummies or state dummies are included. The parameter estimates are all statistically significant

Table 11—Gasoline Taxes, Tax-Exclusive Prices, and Vehicle MPG

	Sample 1. All purchases			Sample 2. Newer purchases		
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Effect from total gas price						
log (gas price)	0.076	0.069	0.065	0.084	0.082	0.076
	(0.017)	(0.018)	(0.019)	(0.026)	(0.027)	(0.028)
Δ in MPG in percent:	0.187	0.169	0.159	0.204	0.201	0.185
5c $\uparrow$ gas price	(0.041)	(0.044)	(0.046)	(0.063)	(0.066)	(0.068)
R^2	0.054	0.056	0.059	0.082	0.084	0.091
Panel B. Separating gas tax and tax-exclusive price						
log (tax-excl. gas price)	0.087	0.085	0.105	0.099	0.111	0.134
	(0.020)	(0.019)	(0.029)	(0.024)	(0.027)	(0.037)
log (1 + tax ratio)	0.151	0.174	0.288	0.201	0.274	0.405
	(0.082)	(0.073)	(0.126)	(0.067)	(0.077)	(0.148)
p-value: $\alpha = \beta$	0.354	0.170	0.080	0.109	0.018	0.030
Δ in MPG in percent:	0.418	0.482	0.798	0.557	0.759	1.123
5c $\uparrow$ gas tax	(0.227)	(0.202)	(0.348)	(0.187)	(0.213)	(0.409)
R^2	0.053	0.055	0.059	0.082	0.085	0.091
Census division dummies	No	Yes	No	No	Yes	No
State dummies	No	No	Yes	No	No	Yes
Observations	52,128	52,128	52,128	30,363	30,363	30,363

Notes: The dependent variable is the log of average household MPG. Columns 1–3 are based on all households who purchased at least one vehicle during past 12 months prior to the survey. The dependent variable is the log of the average MPG across all vehicles purchased during the past 12 months. Columns 4–6 focus on households who purchased at least one vehicle during the past 12 months, and all the vehicles purchased are less than four years old. All regressions include the variables listed in Table 8. We use dummy variables for the categorical variables. Sampling weights are used in all regressions. Clustered standard errors at the state level are reported in parentheses.

and are very similar across the three regressions. The estimates from sample 2 (presented in columns 4–6) are similar across the three specifications, and they are only slightly larger than their counterparts from sample 1. The elasticity estimates provided by the coefficient estimates on the price variable are close to those in several recent studies: Small and Van Dender (2007) estimate a short-run elasticity of 0.044; Gillingham (2010) finds a medium-run (two-year) fuel economy elasticity of 0.09; Klier and Linn (2010) estimate an elasticity of about 0.12 using monthly data.[26]

Panel B shows regressions that separate the gasoline tax from the tax-exclusive gasoline price; columns are analogous to those in panel A. In all six regressions, the coefficient estimate on the tax ratio variable (β) is larger than that on the tax-exclusive gasoline price (α), with the difference being more pronounced using the smaller sample focusing on newer vehicles. The p-value for the hypothesis that consumers respond equally to the two components is 0.08 in column 3 (with all households) and 0.03 in column 6 (with the smaller sample). This comparison is intuitive and is consistent with the persistence explanation: if the differential effect is driven by the durable good nature of automobiles, we would expect a stronger effect among

[26] In all the regressions, the gasoline prices are matched to the month of vehicle purchase. We also estimate the same regressions using the 3-month or 12-month averages of the gasoline price and tax (including the purchase month and months prior to purchase). The results (not reported) are similar to those in Table 11.

Table 12—Gasoline Taxes, Tax-Exclusive Prices, and Household VMT

	Sample 1. Two odometer readings			Sample 2. Reported annual VMT		
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Effect from total gas price						
log (gas price)	−0.497	−0.329	−0.391	−0.274	−0.122	0.108
	(0.11)	(0.113)	(0.133)	(0.156)	(0.123)	(0.284)
Δ in VMT in percent:	−1.631	−1.079	−1.284	−0.868	−0.388	0.343
5c ↑ gas price	(0.359)	(0.372)	(0.435)	(0.496)	(0.389)	(0.901)
R^2	0.447	0.448	0.45	0.361	0.362	0.363
Panel B. Separating gas tax from tax-exclusive price						
log (tax-excl. gas price)	−0.496	−0.329	−0.446	−0.253	−0.066	−0.246
	(0.107)	(0.113)	(0.249)	(0.182)	(0.145)	(0.42)
log (1 + tax ratio)	−0.523	−0.339	−0.593	−0.387	−0.273	−1.423
	(0.304)	(0.21)	(0.809)	(0.334)	(0.147)	(1.3)
p-value: $\alpha = \beta$	0.914	0.950	0.804	0.744	0.246	0.218
Δ in VMT in percent:	−1.722	−1.115	−1.950	−1.231	−0.870	−4.532
5c ↑ gas tax	(1.000)	(0.692)	(2.661)	(1.064)	(0.468)	(4.142)
R^2	0.447	0.448	0.45	0.361	0.362	0.364
Census division dummies	No	Yes	No	No	Yes	No
State dummies	No	No	Yes	No	No	Yes
Observations	28,303	28,303	28,303	61,795	61,795	61,795

Notes: The dependent variable in all specifications is the log of daily household VMT for all vehicles owned. Columns 1–3 are based on households who reported two odometer readings for each of the vehicles owned from the 1995 and 2001 NHTS. Columns 4–6 are based on self-reported annual VMT. All regressions include the control variables listed in Table 9. We use dummy variables for the categorical variables. Sampling weights are used in all regressions. Clustered standard errors at the state level are reported in parentheses.

newer vehicles that have a longer remaining lifetime.[27] Supporting this hypothesis, Busse, Knittel, and Zettelmeyer (2013) find that the adjustment in the new vehicle market to gasoline price changes is primarily in market shares, while it is primarily in vehicle prices in the used vehicle market.

For the VMT analysis, Table 12 presents key parameter estimates as well as the implied changes in gasoline consumption from changes in the gasoline price and tax. The six regressions in panel A include total gasoline prices on the right side, while those in panel B separate tax-exclusive prices from gasoline taxes. The dependent variable in columns 1–3 is the log of household daily odometer-based VMT (sample 1), and that in columns 4–6 is the log of self-reported VMT (sample 2).

The VMT elasticity with respect to gasoline prices from sample 1 ranges from −0.33 to −0.50 in the three specifications. The preferred specification in column 3 with state fixed effects provides an estimate of −0.39. When separating gasoline taxes from tax-exclusive gasoline prices in panel B of Table 12, the coefficient estimates on the key variables are rather close. In additions, the standard errors are quite large, especially when state fixed effects are included in column 3. This could reflect more limited variations in gasoline taxes than for the MPG analysis (recall that the VMT analysis only uses the 1995 and 2001 NHTS because the second odometer

[27] We have estimated equation (4) using older vehicles (four years or older) and we cannot reject the hypothesis of no differential effects from gasoline taxes and tax-exclusive prices.

readings were not collected in the 2009 survey). In all specifications, the coefficient estimate on the tax ratio variable is larger than that on the tax-exclusive gasoline price but none of the differences is statistically significant.

We conduct the same analysis in columns 4–6 based on self-reported VMT. We use average gasoline prices over the same period as the VMT reporting. The VMT elasticity to gasoline prices is -0.27 from column 4, while it is smaller in magnitude and statistically insignificant in columns 5 and 6. The regressions in the second panel separate the gasoline tax from the tax-exclusive gasoline price. There are no statistically significant differential effects on VMT from the tax-exclusive gasoline price and gasoline tax. Nevertheless, when state fixed effects are included, the difference in the two coefficient estimates is quite large in magnitude with equally large standard errors. We conduct additional regressions using self-reported VMT data based on a larger sample that also includes data from the 2009 NHTS. The findings, not reported here, are qualitatively the same. The difficulty in obtaining precise estimates of the VMT responses to gasoline price changes is common in studies using household-level survey data. For example, based on the Consumer Expenditure Survey from 1984–1990, Goldberg (1998) reports imprecise and large estimates of the effects of the gasoline price on quarterly VMT in a unified model of vehicle demand and utilization.

Although we find that vehicle purchase decisions (as reflected in average MPG) respond more strongly to gasoline tax changes than commensurate tax-exclusive price changes, there is no statistically significant evidence of a differential effect for VMT. Recall that we find strong and significant differential effects on gasoline consumption based on the state-level data. Given that it takes time for changes in the MPG of new vehicles to significantly change fleet fuel economy, one might find these two sets of findings to be at odds with each other. We reconcile them from the following three angles.

First, the limited variations in gasoline taxes in the VMT analysis could prevent us from estimating precisely a differential effect. The odometer-based VMT analysis, which includes the years 1995, 1996, 2000, and 2001 (from 1995 and 2001 NHTS survey), contains only 22 tax changes (15 percent of state-year observations). The average change (in magnitude) is 2.43 cents, in 2008 US dollars. In our state-level analysis, there are 488 gasoline tax changes (about 24 percent of state-year observations) and the average change (in magnitude) is 3.64 cents. Thus, tax changes are larger and more common in the state-level analysis than the household-level analysis.

Second, the differential effects found in state-level data are based on annual observations while our household-level VMT analysis are based on the few months (on average three months) between the two odometer readings. The differential effect in VMT, if it exists, is likely to be smaller in the short term because there are fewer accessible adjustment margins. A large portion of VMT is determined by job and housing locations as well as availability and access to public transit. These factors are difficult to change in the short-term.[28]

[28] In the long run, because of adjustment costs, taxes could have a larger effect than tax-exclusive prices on consumer location decisions (and, hence, travel distance and possibly travel mode). The long-run response remains an open question.

Third, the state-level analysis may include margins other than MPG and VMT, which were the focus of the household-level analysis. For example, multi-vehicle households may reallocate driving across vehicles when gasoline prices or taxes change. Unfortunately, we lack sufficient gasoline tax variation in the household-level data to investigate these possibilities. Nevertheless, the fact that the state-level results could reflect a wider range of behavior than the household-level results may partly explain why we do not detect as strong a response in the household-level data as in the state-level data.

IV. Implications

Our central and robust finding of differential responses to gasoline taxes and tax-exclusive prices has important implications for the effectiveness of using gasoline taxes to address climate change, air pollution, and energy security. In particular, gasoline taxes would be more effective at reducing gasoline consumption than suggested by previous empirical estimates of the effect of gasoline prices on gasoline consumption. The results also have implications for the implicit discount rate and the tax revenue from gasoline taxes, which we discuss in this section.

A. *Implicit Discount Rate*

Our analysis points to an empirical strategy to confront a challenging identification problem in estimating implicit discount rates in consumer decisions. To understand this, consider consumers' vehicle purchase decisions when facing an array of choices that have different upfront costs (i.e., purchase price), future operating costs (e.g., fuel costs), and other vehicle characteristics. Due to the durable good nature of automobiles, a rational consumer makes the decision based on total (discounted) expected costs and total (discounted) utility to be derived from the vehicle. To examine how consumers trade upfront purchase costs with future operating costs, researchers often estimate the implicit discount rate in a vehicle demand or hedonic framework. A high discount rate is interpreted as evidence that consumers fail to consider properly future costs. The undervaluation of future fuel cost savings is a manifestation of the *energy paradox*. If present, it could hinder the effectiveness of gasoline taxes and hence lend support for CAFE standards. Whether, and to what extent, the energy paradox holds in the automobile sector is still a contentious empirical issue.[29] This is due partly to the identification challenge researchers face in the empirical analysis because neither consumers' discount rates nor their expectation of future gasoline prices is observed. Consequently, it is not possible to estimate implicit discount rates without making assumptions on consumer expectations of future gasoline prices.

However, separating gasoline taxes from tax-exclusive gasoline prices can aid the identification of the implicit discount rate. The central assumption is that consumers

[29] Allcott and Wozny (forthcoming), Busse, Knittel, and Zettelmeyer (2013), and Sallee, West, and Fan (2010) are among recent studies using very rich datasets to investigate this issue. Helfand and Wolverton (2011) offers a recent review.

treat taxes as more persistent than tax-exclusive prices, which is consistent with the main results and the estimates of the AR(1) specification described in Section IIE. Under this assumption, approaches used in the recent literature could be modified by decomposing the retail gasoline price into the tax-exclusive price and the tax. If gasoline tax changes are different from gasoline price changes in both persistence and salience as we documented above, the implicit discount rate based on the tax component should provide a lower bound on the implicit discount rate for how consumers value future fuel costs. In addition, the difference in salience is consistent with the presence of consumer inattention as one of the underlying causes for energy paradox (Allcott and Greenstone 2012). We leave the investigation of these issues to future work.

B. *Tax Elasticity of Tax Revenues*

Finally, our approach may have implications for fiscal policy related to gasoline taxes. As an illustration, we calculate the change in tax revenues associated with a \$0.05 per gallon increase in federal gasoline taxes based on (i) a naïve estimate using the tax-inclusive semi-elasticity in column 10 in Table 2; and (ii) the corresponding tax semi-elasticity estimate from column 10 of Table 2. The naïve estimate implies that a \$0.05 per gallon increase in state gasoline prices would increase tax revenues approximately 12.4 percent in 2008. This corresponds to tax revenue of about \$4 billion, which is about one-quarter of the deficit for the Highway Trust Fund forecasted by the Congressional Budget Office. Using the separately estimated tax and price coefficients, a \$0.05 per gallon tax increase would raise tax revenue by 11.2 percent. Interestingly, the naïve prediction does not substantially overestimate the implied increase in tax revenues associated with a gasoline tax increase. Gasoline demand is sufficiently inelastic and gasoline taxes are sufficiently far from the revenue maximizing level to make the distinction between techniques less relevant for fiscal policy.

V. Conclusion

Despite multiple policy goals that the gasoline tax can help to achieve, the United States taxes gasoline at the lowest rate among industrialized countries. In 2009, average state and federal gasoline taxes were \$0.46 per gallon, compared to \$3.40 per gallon in the United Kingdom. Heightened environmental and energy concerns, a record national budget deficit, and an insolvent Highway Trust Fund have renewed interest in raising the gasoline prices.

This paper estimates consumer responses to gasoline taxes directly by distinguishing gasoline taxes and tax-exclusive gasoline prices. We examine the short-run impacts of taxes on gasoline consumption, vehicle miles traveled, and vehicle choices using both state-level and household-level data. We find strong and robust evidence that gasoline tax changes are associated with larger changes in gasoline consumption and vehicle choices than are commensurate changes in tax-inclusive gasoline prices.

The finding that not all variations in gasoline prices are created equal has important implications for transportation and tax policies. First and foremost, our work indicates that fuel taxes may be a more effective measure for reducing gasoline consumption or inducing consumers to adopt more fuel efficient vehicles than previously thought. Second, our research shows that gasoline tax changes could provide a useful means of identifying the implicit discount rate and to quantify the extent of an energy paradox in automobile demand. Third, our estimates suggest that traditional analysis on gasoline taxes may slightly overestimate the fiscal benefits of raising the gasoline tax.

Our research points to three questions which warrant further investigation. First, recent studies have estimated that the optimal gasoline tax in the United States is more than twice as large as the current level (Parry and Small 2005; and West and Williams 2007). One of the key inputs for the analysis is the long-run consumer response to gasoline taxes, using the long-run price elasticity as a proxy. Our analysis provides evidence that the effect of current and lagged taxes is greater than the effect of current and lagged tax-inclusive prices, but the precise long-run estimates and their implications for the optimal gasoline tax are unknown.

Second, we provide some evidence that the greater persistence of tax changes as well as the greater salience of tax changes (relative to the same-size tax-exclusive price changes) could contribute to our main findings. Further work is needed to assess the relative importance of these and other potential factors. Perhaps most importantly is the question of generality. Our finding suggests that it may be important to consider the source of the price variation when estimating price elasticities of demand and conducting policy analysis for other goods and services.

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