The Effect of Fuel Price Changes on Fleet Demand for New Vehicle Fuel Economy

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Abstract

New vehicle purchases by private companies and government agencies, or "fleet" buyers, represent a significant percentage of overall new vehicle sales in the United States. Yet little is known about fleet demand for new vehicle fuel economy including how it responds to fuel price changes. Using unique disaggregated data on fleet and household registrations of new vehicles from 2009 to 2016, we estimate how fleet demand for new vehicle fuel economy responds to fuel price changes. We find that fleet purchases of low fuel economy vehicles fall relative to high fuel economy vehicles when gasoline prices increase, a finding that is consistent with fleet buyers taking into account capitalization of fuel costs in the second-hand market. Our estimates imply that raising gasoline prices by one dollar would increase fuel economy of new vehicles acquired by fleet buyers by 0.33 miles per gallon. We estimate a similar response for household buyers during the same period. This result justifies basing fuel economy responses to fuel cost changes on household data alone, an assumption widely used in the vehicle demand literature and the fuel economy valuation literature. We also find, however, that the response to fuel price changes varies across the types of fleet buyers: rental companies respond strongly to fuel price changes, whereas commercial and government buyers are insensitive. Our estimates imply that an increase in the federal gasoline tax would modestly increase fuel economy of vehicles bought by households and rental companies but would have little to no impact on fuel economy of vehicles bought by non-rental companies and governments.

Keywords: passenger vehicles, fuel prices, fleet vehicle demand

JEL codes: H25, L11, L33, L62, Q41

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1 Introduction

How do vehicle fleet organizations, such as rental car companies, decide which vehicles to buy? The demand estimation literature has provided extensive evidence on the determinants of household vehicle demand. Yet little is known about "fleet" demand – rental car companies, commercial sources, and all levels of government – even though fleet demand accounts for nearly one-fifth of new light-duty vehicle registrations every year in the United States.[1]

The social welfare effects of fuel consumption policies such as Corporate Average Fuel Economy Standards or gasoline taxes depend on vehicle demand from all buyers – including fleet buyers. Existing models of the light-duty vehicle market that examine the welfare implications of fuel consumption policies assume that household and fleet buyers respond in the same way to changes in the cost of vehicle ownership and use. Fleet demand, however, may be different than household demand. Our study addresses how fleet buyers make decisions about new vehicles and what types of vehicles they purchase. We empirically evaluate how new vehicle fleet sales (measured by vehicle registrations) respond to changes in fuel prices. We then expand our analysis by estimating the effect of fuel price changes on household new vehicles purchases, which allows us to compare the fleet demand response to household demand response. Our results provide guidance on how to model fleet demand for fuel economy when evaluating fuel consumption policies.[2]

The literature on fuel consumption policies and passenger vehicle demand has focused on estimating vehicle demand for individual household buyers in the retail market and, based on those estimates, has conducted welfare predictions of fuel consumption policies for the entire new passenger vehicle market (Bento et al. 2009; Jacobsen 2013a). Given that fleet vehicle demand constitutes a significant share of overall new passenger vehicle demand, finding a significant deviation in fleet demand from household demand would suggest past studies have misestimated market-wide demand for fuel cost savings. Similarly, rejecting such deviation would justify the assumptions of identical demand used in previous studies. Other studies have assumed that household and fleet buyers have identical preferences for fuel cost savings and other vehicle attributes (Berry et al. 1995; Goldberg 1998; Busse et al. 2013). Whether the latter studies provide unbiased estimates of vehicle demand and whether the former can

[1]The share of fleet vehicles among total new light-duty vehicles registered was 19 percent in 2010, and has dropped slightly since then to 15 percent in 2016.

[2]Government agencies have stated an interest to incorporate vehicle demand in their analysis of fuel economy and greenhouse gas standards. One example is in the regulatory impact analysis (RIA) for the final rulemaking for the 2017-2025 light-duty vehicle greenhouse gas emission standards and CAFE standards. In this document, the agencies discuss the value of incorporating vehicle demand models in analyses of these regulations (EPA 2012).

be extrapolated to the entire vehicle fleet is not clear without evidence about fleet vehicle demand. This paper takes the first step to address these issues.

In addition, this analysis is relevant to other papers that assume no differences between household and fleet buyers, including studies that estimate consumer demand for fuel cost savings (Leard et al. 2017b) and studies estimating passenger vehicle demand while controlling for fuel cost savings (Reynaert 2015; Klier and Linn 2012; Whitefoot et al. 2017). Other studies explore counterfactual fuel consumption policies such as fuel taxes and carbon taxes that affect fuel prices (Klier and Linn 2010; Klier et al. 2017; Li et al. 2009). These studies do not differentiate between household and fleet demand responses to fuel price changes. Disaggregating demand by buyer type provides a more detailed and accurate understanding of the distributional impacts associated with fuel consumption policies, which can be critical for having these policies gain political favor.

Fleet buyers may be either sensitive or insensitive to fuel cost changes for various reasons. Government purchases may be insensitive to fuel price changes if a principal-agent problem is present. Federal regulations and subsidy incentives may discourage government buyers from responding to energy price changes (Li et al. 2015).[3] Governments may have specific vehicle uses and requirements that limit their choices, also causing government and commercial fleet buyers to be insensitive to fuel cost changes. As for state and local governments, their choices are still subject to automobile management regulation. In addition, unlike private companies, government buyers do not have the same incentive to purchase high-fuel economy vehicles.[4] Federal fleets and local fleets can be funded via various grants, so that government agencies have the incentive to utilize the funding regardless of the fuel economy of the vehicle. For example, the University of Colorado's police department vehicle fleet is funded using a Department of Justice grant, and the Los Angeles fire department adds to their fleet using a Federal Emergency Management Agency grant.[5] If the decisions about fuel economy are

[3]Li et al. (2015) find that energy prices do not affect bus procurement decisions primarily because of "buy America" subsidies for bus purchases and also because of various political factors. Among federal and local US governments, 70 percent of motor vehicles (light-duty and other) are owned by agencies and 30 percent are leased via the US General Service Administration: https://www.gsa.gov/cdnstatic/Federal%20Fleet%20Management%20101.pdf. US government fleets are subject to multiple regulations. The US Federal Vehicle Standard classifies specific vehicle types and vehicle models for federal agencies to purchase: https://www.gsa.gov/acquisition/products-services/transportation-logistics-services/vehicle-buying/federal-vehicle-standards. The following link shows specific vehicles that federal agencies can purchase: https://vehiclestd.fas.gsa.gov/CommentCollector/Home. In addition, the government fleet is subject to motor vehicle management (federal and local), GSA fleet (for federal leasing), etc. that further restrict the purchase decisions of government vehicle buyers.

[4]By Section 503 of Title 40, U.S. code, federal agencies can request to "exchange" their old fleet and replace with a similar vehicle: https://www.gsa.gov/policy-regulations/policy/vehicle-management-policy/exchangesale-of-motor-vehicles

[5]https://www.government-fleet.com/funding.

removed from budget considerations by the overseeing government agency, then fuel savings will not be fully considered by government buyers (Arrow 1985; Graus and Worrell 2008; Adland et al. 2017).

Rental car companies, constituting about 80 percent of fleet demand, can be sensitive or insensitive to fuel cost changes. On the one hand, "dumping" incentives from vehicle manufacturers and "buy-back" options in contracts with manufacturers may cause rental car companies to not respond to fuel price changes, or respond less than household vehicle buyers. From discussions with large manufacturers, we learned that some contracts specify that rental car companies purchase models that are not selling well to household buyers. Manufacturers can specify certain models they are willing to buy back, which would dampen the effect of fuel price changes on rental car companies' purchasing decisions. On the other hand, economic factors are important for rental car companies when they choose new vehicles to purchase. We were informed by several representatives of rental car companies that profits in the rental car industry depend critically on the resale value of vehicles in the used car market after 12 to 18 months as rentals. Resale values are strongly influenced by fuel costs, especially during periods of changing gasoline prices (Busse et al. 2013; Sallee et al. 2016). Therefore, rental companies are likely to profit from buying vehicles that will be in high demand in the used car market, where households make up nearly all of the demand.[6] To the extent that this effect dominates, we expect rental companies to be quite sensitive to fuel costs in vehicle purchase decisions. Whether they are sensitive to fuel price changes, and whether they are more or less sensitive than household buyers is an empirical question.

In this paper, we estimate the effect of fuel cost changes on the number and type of vehicles purchased by household and fleet buyers. We use detailed quarterly new vehicle registrations data for household and fleet buyers from 2009 to 2016. For 2015 and 2016 only, we also have fleet vehicle registrations broken out by rental, commercial, and government categories. We adopt a similar methodology to that in Klier and Linn (2010) and Leard et al. (2017a), controlling for potential unobserved vehicle characteristics by exploiting highly disaggregated data. We control for demand factors specific to a vehicle stub in a particular model year and market year and the type of buyer. For example, our fleet registrations specification has separate fixed effect of different types of buyer for a Honda Accord LX 2016, coupe, gasoline powered, front-wheel drive, 2.4-liter displacement engine sold during the fourth quarter of 2015 through the third quarter of 2016.

[6] Resale values of 1–3 year old vehicles are especially sensitive to changes in gasoline prices, where used vehicle buyers are willing to pay about 93 cents for every dollar of fuel cost savings (Allcott and Wozny 2014).

For our sample period, we find that household buyers and fleet buyers respond to fuel cost changes in similar ways. We find that on average, a one dollar increase in per mile fuel costs reduces demand by 7 percent for household buyers and 6 percent for fleet buyers. We cannot reject the hypothesis that changes of vehicle demand driven by fuel price variation are indistinguishable between an average household buyer and an average fleet buyer. Our results provide the first empirical justification for not separating these two groups of vehicles – a practice commonly used in previous vehicle demand literature and fuel economy policy literature as discussed above. From 2015 and 2016, we find that the three distinct types of fleet buyers have different responses to fuel cost changes: rental companies are twice as sensitive to fuel cost changes relative to the average response among all fleet buyer types. In contrast, commercial companies and government agencies are unresponsive to fuel cost changes.

Our results contribute to guiding the design and analysis of fuel consumption policies in several ways. First, our estimates of the response to fuel price changes contribute to the literature on how vehicle purchase decisions made by organizations respond to energy price changes.[7] Our study provides the first detailed analysis of new passenger vehicle demand for fleet buyers, which is important for understanding the market structure of new passenger vehicles and effects of fuel consumption policies for new vehicles. Our results imply that raising gasoline prices by one dollar through tax policy in 2015 would increase fuel economy of new vehicles acquired by fleet buyers by 0.33 miles per gallon, or 1.5 percent of average new vehicle fuel economy. Second, our study is the first to compare the behavior of household buyers and fleet buyers in the new light duty vehicle market. We find that fleet buyers have a similar response to fuel price changes as household buyers. Our study, therefore, offers justification for the assumption that it is not necessary to distinguish between household and fleet buyers in analyses of the fuel economy response to fuel cost changes.[8] Our results also affirm that gasoline prices have only a modest short-run effect on new light duty vehicle fuel economy implying that policies like raising gasoline taxes may have a limited short-run impact on reducing fuel consumption of newly purchased vehicles.

[7] The only other paper analyzing the responsiveness of vehicle purchases made by organizations is by Li et al. (2015), who find no effect of diesel price changes on the US bus fuel economy. Most other works on heavy-duty trucks have instead focused on fuel use and travel intensity (Leard et al. 2015; Cohen and Roth 2017) or vehicle attributes other than fuel cost savings (e.g., Rust 1987 and Wollmann forthcoming). Moreover, it is unclear whether inferences for heavy-duty trucks demand are applicable to passenger vehicle fleet demand.

[8] Another commonly used assumption in these studies is the random walk assumption of fuel prices. Recently, Anderson et al. (2013) offer justifications based on household survey responses for using the current gasoline price as an estimate of the expected gasoline price.

2 Background and Data

2.1 Background of Fleet Vehicle Demand

Panel A of Figure 1 depicts total vehicles purchased and registered by fleet buyers from 2009 to 2016. In 2010, fleet buyers accounted for 19 percent of new vehicle registrations in the United States. In the first quarter of 2010, fleet buyers registered 0.6 million new passenger vehicles, compared with to 1.9 million registered by household buyers in the retail market. New vehicle registrations have increased over time since the 2008 recession, much more so for household buyers than for fleet buyers. Nevertheless, toward the last year of our sample, fleet buyers still represent a significant market share in equilibrium, accounting for about 15 percent of the overall new vehicles registered in 2016.

Panel B of Figure 1 separates fleet registrations into three types of fleet buyers – rental companies, commercial companies, and government buyers – by quarter for 2015 and 2016. Rental company purchases account for the largest share. In the first quarter of 2015 alone, rental companies registered 580 thousand new vehicles, accounting for 86 percent of the overall 670 thousand new vehicles registered by fleet buyers. Commercial fleets make up 8 percent of the total and government buyers 5 percent. Panel B of Figure 1 also shows that equilibrium sales of vehicles to commercial and government fleets are relatively stable over time, but that rental companies purchase more new vehicles at certain times of the year than others. Many more vehicles are sold to rental companies during the first quarter of every year, which is the slowest time in the retail market, and fewer vehicles are sold in the last quarter of the year when new models are coming onto the market. In our interviews with car manufacturers, we were informed that rental companies contract for some vehicles from the auto manufacturers on an annual basis, but they also make and change orders throughout the year.

In Table 1 we summarize possible reasons explaining why fleet demand for new vehicles may or may not respond to fuel price changes. Reasons include different vehicle uses, differences in ownership periods, contract buyback options, and principal-agent problems. For example, commercial and government buyers may select from a relatively limited set of vehicles with special features that suit a specific need, thus having a limited response to fuel price changes when purchasing new vehicles. In contrast, rental vehicles may be heavily driven during their rental period (prior to being sold in the used vehicle market), implying that rental car companies have more incentive account for fuel costs when making purchases. Furthermore, fleet vehicles may last longer and be driven more miles over their lifetime given the types of vehicles bought by fleet buyers. Light trucks are typically driven more miles over their lifetime (Lu 2006). To address this possibility, in Figure 2, we plot the distribution of body style for each buyer type. The distributions suggest that commercial and government buyers appear to have lower demand for sedans than retail buyers and rental companies. They have a higher demand for cab and chassis, van, and pickup trucks than household buyers in the retail market and rental companies in the fleet market. In addition, all fleet buyers tend to have low demand for certain makes and models. For example, in 2016, household buyers registered 1,576 new Jaguar F-Pace RSTs, while rental and leasing companies in total registered 3, commercial companies registered 1, and government units registered none.

Moreover, government buyers may be restricted in their choice due to regulations or fiscal policies.[9] Li et al. (2015) found that US bus purchases were insensitive to energy price changes because of federal "buy American" programs and other regulations and tax incentives. In Figure 3, we plot the distribution of domestic and foreign light-duty vehicles registered by buyer type from 2015 to 2016. Both individual households and rental companies purchase vehicles by foreign manufacturers at relatively high rates. But commercial companies purchased disproportionately more domestic vehicles, and government purchases were 95 percent domestic. Government vehicles, in particular, that are purchased with tax payer dollars are expected or required to be domestically produced. These constraints are likely to make government agencies less sensitive to market conditions such as fuel prices than other vehicle buyers.

Rental car companies, making up the largest share of fleet vehicles, have a number of influences that will affect how they respond to fuel price changes in their choices of new vehicle. Table 1 describes some of the interactions rental companies have with automobile manufacturers, including, manufacturers "dumping" of less popular vehicles with the rental companies, and options for automobile companies to "buy-back" from the rental companies at agreed upon prices. Our interviews with car rental companies suggest that rental companies contract with car manufacturers for large number of limited set of specific vehicle models. In some cases, the manufacturers agree to buy them back after a certain time period or mileage accumulations at agreed upon prices. The limited number of models suggest that the rental companies might not be particularly sensitive to fuel costs in their choices of vehicles. Their choices are likely to be constrained by what the manufacturers offer them. However, there are also reasons that rental car companies may consider fuel costs in their decision of vehicle purchases.

[9] For example, the Executive Order 13693 in 2015 imposes a fuel economy requirement for federal vehicle purchases. Details can be found at https://obamawhitehouse.archives.gov/the-press-office/2015/03/19/fact-sheet-reducing-greenhouse-gas-emissions-federal-government-and-acro.

In Figure 2, we plot the distribution of body style for each buyer type. The distribution of vehicle body style in the rental market resembles that in the retail market. This evidence appears to suggest, in a broad sense, that rental companies and individual household consumers choose from similar types of vehicles.[10] Rental companies often sell their vehicles after a relatively short period, which is roughly one year or 25,000 miles, either back to car manufacturers or to the used car market. The resale value in the used car market depends, among other things, on gasoline prices and the fuel economy of the vehicle. There is a strong correlation between used car prices, fuel economy and gasoline prices (Busse et al. 2013; Allcott and Wozny 2014; Sallee et al. 2016). Therefore, we expect the size and fuel economy of rental company vehicle purchases to be inversely correlated to the gasoline price.[11] For example, if gasoline prices are high or increasing, rental companies will want to buy more fuel efficient vehicles which will be in demand and command a high price in the used car market. This response is similar to what we expect from individual household buyers in the retail market.

2.2 Data

Our primary data are national quarterly registrations for all light-duty vehicles sold in the United States between the third quarter (Q3) of 2009 and the fourth quarter (Q4) of 2016 from IHS Automotive.[12] New vehicle sharply fell during the 2008 recession but had began to gradually return to the pre-recession level around Q3 2009. To avoid the effects of the recession, we selected the third quarter of 2009 as the first quarter of observation and focus much of our analysis on later years.[13]

The registrations data are disaggregated by retail vehicles and fleet vehicles. The "retail" registrations type refers to the number of registrations by an individual vehicle buyer or leaser (e.g., the head of a household), hereafter *household buyers*, who make a transaction via a retail channel, for example, purchasing a Camry from a local Toyota dealer. The "fleet" registrations type refers to the number of vehicles registered by private companies and government agencies for their commercial or governmental activities.

[10]For example, Enterprise Inc. lists 18 vehicle classes for small cars, 13 vehicle classes for SUVs, 2 classes of light-duty trucks, and 6 classes of light-duty vans in the United States. More details can be found at https://www.enterprise.com/en/car-rental/vehicles/us.html. Other companies have similar vehicle listings.

[11]A discussion of the importance of resale value to rental companies can be found at http://www.autorentalnews.com/channel/remarketing/article/story/2015/01/2015-resale-forecast-for-cars-vans-and-trucks.aspx.

[12]Vehicle registrations represent both purchases and leases as in other studies on vehicle demand, e.g. Allcott and Wozny (2014).

[13]In Section 4.4, we test the robustness of our results by omitting time periods close to the end of the great recession.

Our data from Q1 2015 through Q4 2016 are further disaggregated by fleet buyer type: rental companies, commercial companies, and government. Rental companies refer to companies that rent passenger vehicles to individuals.[14] Commercial companies refer to other private entities that are not rental companies and purchase vehicles for their employees for business use. Passenger vehicles registered by Allstate for their employees, for instance, would fall into this category. Government buyers refer to government agencies that register vehicles. For example, a passenger vehicle registered by the U.S. Secret Service would fall into this category. Information on fleet buyer type gives us a total of four types of registrations in total for the eight quarters in 2015 and 2016.

In addition to buyer type, this data set is highly disaggregated by vehicle type. We define a unique vehicle type, hereafter "vehicle stub", by a combination of model year, make, model, series, sub-series, fuel type, drive type (e.g., all-wheel drive), body style, and the number of liters of engine displacement. As an example, the data include distinct observations for retail and fleet registrations of a 2016 Honda Accord EX gasoline-powered front-wheel-drive sedan with a 2.4-liter engine.

We link these vehicle registrations data with vehicle fuel economy ratings from the U.S. Environmental Protection Agency (EPA). We assign vehicle fuel economy based on the weighted average city/highway rating and link this information to registrations data by vehicle stub and model year. We assign each IHS observation with an EPA fuel economy rating using all the vehicle identifiers available in IHS. We also obtain non-fuel economy characteristics from Ward's Automotive for the same time span.[15]

We further complement our analysis with fuel price data from the U.S. Energy Information Administration. We collect national quarterly prices of gasoline and diesel fuel from 2009 to 2016 for gasoline- and diesel-powered vehicles. To account for fuel costs for plug-in hybrid and electric vehicles in our sample, we collect quarterly electricity prices for the residential sector. We compute cost per mile (in 2016 dollars) for each vehicle type using fuel economy ratings and quarterly energy prices for gasoline-powered, diesel-powered, and electric vehicles. For plug-in hybrid vehicles, we follow the methodology in Leard et al. (2017a) and use a weighted average cost per mile using both gasoline and electricity prices.[16]

[14] Rental companies sometimes also offer heavy-duty truck rentals. In this paper, we focus on their demand for passenger vehicles only.

[15] We assign non-fuel economy characteristics including horsepower, weight, wheelbase, length, width, and height to each IHS observation.

[16] We first impute fuel economy ratings for gasoline mode (i.e., miles per gallon or MPG) using the combined fuel economy equivalent ratings (MPGe), energy efficiency at electricity mode (i.e., miles per kilowatt or MPK), and the fraction of electricity usage. We then compute the average cost per mile using MPG in gasoline mode, MPK in electricity mode, the quarterly average gasoline price, the quarterly average electricity price, and the predicted fraction of electricity usage assumption used by the EPA.

To examine differences in other vehicle attributes such as horsepower and weight, we merge vehicle characteristics data from Wards Automotive for 2008–2017 model year vehicles. These data are highly disaggregated by vehicle stub that we have defined above, so we are able to perform a clean match based on each attribute identifier.

2.3 Summary Statistics and Suggestive Evidence

Table 2 reports summary statistics for two-year periods from 2009 to 2016. We use vehicle registrations to represent equilibrium sales. Panel A reports summary statistics for individual households, and panel B reports details for all fleet buyers. The average number of registrations per vehicle stub for household buyers has been stable throughout the sample and increasing in 2015 and 2016. The average number of registrations for fleet buyers was stable before 2015 and has decreased since 2015. These differences reflect changes in the total number of registrations made by each buyer as well as the unique number of stubs registered. As the total number of registrations for fleet buyers has remained stable during the sample period (see Figure 1), the decline in the number of registrations per vehicle stub suggests that fleet buyers have shifted to purchasing a greater variety of stubs over time.

To preview the identifying variation we exploit in this paper, we plot in Figure 4 the temporal changes in equilibrium market shares for vehicles by fuel economy groups and temporal changes in gasoline prices from 2009 to 2016. We plot changes for household buyers in panel A for both passenger cars and light-duty trucks. Using body style information, we define passenger cars to include sedans, coupes, convertibles, and hatchbacks. They are, on average, more fuel efficient than light-duty trucks (SUVs, vans, cab and chassis, and pickup trucks). As as gasoline prices increase from Q4 2011 to Q2 2012, passenger cars experienced a moderate increase in market share. In contrast, light-duty trucks experienced a roughly 10 percent decrease in market share for household buyers in the retail market. Similarly, when gasoline prices increased from Q3 2010 to Q2 2011, passenger cars gained market share in the retail market.

Based on this visual evidence, we expect demand shifts in response to fuel price changes. For example, as fuel prices increase, low fuel economy vehicles lose in relative market share, and high fuel economy vehicles gain market share. We build our identification strategy to capture the demand shift of this nature and test this in Section 3.

Next, we plot changes for fleet registrations in panel B of Figure 4. Fleet buyers as a whole show greater variation over time in vehicle purchases than household buyers in the retail market. This pattern is expected because fleet buyers tend to buy vehicles in large volumes at various times through the year. The data confirm that equilibrium sales to fleets are highest in the first quarter of every year when equilibrium sales to the retail market are sluggish, and lowest in the third and fourth quarters when equilibrium sales to the retail market are the highest (see Figure 1). The response to fuel price changes among fleet buyers in panel B appears different than it is for retail buyers. For example, as gasoline prices increase from Q4 2011 to Q2 2012 as shown in Panel B, initially truck shares decline and car share rose, yet the truck share started to decline strongly in Q1 2012.

We further examine fleet purchase patterns in panel C. Most changes in new vehicle purchases appear to come from rental companies, which make up the largest share of the fleet buyer market. Light truck registrations were trending upward and car shares were trending downward over the two-year period. Leading up to this period, fuel prices had been dropping steeply and perpetually low prices could lead to the pattern we see in panel C for rental cars. There is little visual evidence suggesting commercial companies and government units respond to fuel price changes. Equilibrium shares of cars and trucks remained relatively constant over time, with a slight trend downward for cars and up for trucks.[17] Later in Section 4.3, we conduct a few fuel price simulations based upon our estimation results, and we obtain results consistent with patterns shown in this figure.

3 Empirical Strategy

Our approach is to quantify the short-term responses of new vehicle demand to fuel price changes. Taking an approach similar to that used in Klier and Linn (2010) and Leard et al. (2017a), we begin by estimating the reduced-form relationship between the number of new passenger vehicle registrations q_{irt} and fuel costs (dollars per mile) for new vehicle i purchased in quarter t for a particular type of buyer r (retail or fleet). We estimate the following equation separately for vehicles registered by individual households and vehicles registered by fleet buyers:

$$\ln q_{irt} = \beta_r fc_{irt} + \boldsymbol{X}_{irt}\boldsymbol{\gamma}_r + \varepsilon_{irt} \tag{1}$$

where fc_{irt} is the vehicle's fuel costs, $\boldsymbol{X}_{irt}$ is a vector described next, and ε_{irt} is the error term. Our interest is to estimate parameter β_r. The fuel cost variable fc_{irt} is the ratio of vehicle i's fuel price in quarter t registered by buyer type r, fp_{irt},to the fuel economy rating of vehicle i in model year my, $mpg_{ir,my}$. [18] Vehicle i is a unique vehicle stub including model

[17]We find similar trends by examining vehicles with different fuel economy in Appendix Figure A.1. Appendix Figure A.2 previews some potential results between fuel prices and average fuel economy.

[18]Vehicle i's fuel price in quarter t depends on vehicle i's engine. Vehicle i's quarterly fuel price can be the gasoline price, the diesel price, the electricity price, or a combination of the gasoline price and the electricity price. For electric vehicles (EVs), the fuel cost is the ratio of the electricity price and the energy consumption

year. It represents a unique combination of model year, vehicle make, model, series, sub-series, fuel type, drive type, body style, and the number of liters of the engine displacement. (See Section (2.2) for details and examples.)

In Equation (1), we include multiple sets of fixed effects in vector $\boldsymbol{X}_{irt}$ to control for unobserved characteristics possibly correlated with fuel costs. Vector $\boldsymbol{X}_{irt}$ includes the fixed effects of 30 quarters in our sample to capture all unobserved aggregated supply and demand shocks. We estimate Equation (1) separately for different buyer type, so this fixed effect is also, in practice, further interacted with buyer type (retail or fleet). These quarterly fixed effects are likely to be different for retail and fleet vehicles. Figure 1 shows the different cyclical patterns for the two vehicle types. Retail vehicle registrations from individual households tend to peak early in the market year, and fleet vehicle registrations tend to peak at the beginning of the calendar year.

Second, vector $\boldsymbol{X}_{irt}$ includes a fixed effect for each vehicle stub i (including model year) and interacted by market year $m(t)$. We define a market year from September of the previous calendar year (Q4) to August of the current calendar year (Q3) to identify the sales period during which vehicles with a new model year are usually offered. For any vehicle i, carmakers usually adjust vehicle characteristics such as horsepower or the type of entertainment system for a particular model year before the production cycle starts. Once production starts, for example, for model year 2015, carmakers do not further adjust main features for vehicle i in that model year. Including vehicle stub fixed effects (which includes model year) allows us to control for unobserved vehicle characteristics that are constant within a model year and quantify how the number of each type of vehicle registered responds to fuel cost changes stemming solely from fuel price changes. We further interact vehicle stub i with market years $m(t)$ to compare vehicles offered within a market year.

Moreover, our sample spans a period during which fuel economy standards are increasing and potentially binding for all manufacturers. Fuel price changes may possibly cause manufacturers to adjust prices to maintain a compliant sales mix.[19] Equation (1) incorporates both of these supply-side responses since we do not control for temporal changes in new vehicle prices.

For each buyer type, we identify the parameter of interest β_r by exploiting variation in fuel prices over four quarters for a particular vehicle stub within a market year. For example, consider Honda Accord Model Year 2015 EX gasoline powered front-wheel-drive sedan with

rate. For plug-in hybrid vehicles, the fuel cost is a weighted average of fuel costs using the gasoline mode and fuel costs using the electricity mode. See the Section 2.2 for more details of fuel economy ratings for plug-in hybrids and EVs.

[19] Leard et al. (2017a) argue that this may dampen the effect of fuel price changes on market shares.

a 2.4-liter engine purchased in the market year 2016. First, within this vehicle stub and market year 2016, we observe fuel price changes over four quarters and changes in vehicle registrations. For a particular type of buyer, our parameter β_r is identified from computing changes in fuel prices within that market year, i.e., variation in fuel prices between Q4 2015 to Q3 2016 for that vehicle.

For each buyer type, the magnitude of the parameter of interest β_r informs us how vehicles with different fuel economy respond to fuel price variation induced by the above mechanism, i.e. the fuel price variation within stub and market year. Take, for example, the effect of a gasoline price change on the cost per mile of a 20 miles per gallon SUV and a 40 miles per gallon hybrid sedan. A $1 per gallon increase in the gasoline price raises cost per mile of the SUV by 5 cents and the hybrid by 2.5 cents, making the SUV relatively expensive to drive. This change in fuel price reduces the demand for the SUV relative to the hybrid (although both could decrease in response to increasing gasoline prices). The demand shift results in a movement along the new vehicle supply curves, causing manufacturers to adjust new vehicle prices.

The interactions of stub (including model year) by market year by registrations type play important roles in identifying β_r. The interactions control for all physical characteristics of a vehicle that do not vary over the model year. This avoids the need to control for other determinants of demand, such as weight and horsepower, because the β_r coefficients are identified by within-market year fuel price variation interacted with the vehicle's fuel economy. The interactions also control for unobserved demand or supply shocks that do not vary over the market year. For example, household and fleet perceptions about brand quality typically change little within a year.

An important distinction between our estimating equation and those from the previous studies is that we allow the coefficient of interest, β_r, as well as both sets of fixed effects to vary flexibly by the two main types of registrations, that is, household registrations versus fleet registrations. In Section 4.2, we further allow the coefficient of interest, β_r, as well as the above sets of fixed effects to vary by all four types of registrations from 2015 to 2016: households, rental, commercial, and government registrations. Vehicle-level time-invariant preferences and aggregate time-varying shocks likely differ considerably by types of registrations. Our flexible fixed effects control for these differences. Allowing β_r to vary by types of registrations also allows us to test empirically whether household and fleet registrations respond differently to fuel cost changes.

We expect the coefficients of interest, β_r, to be negative. Increasing gasoline prices raise the cost per mile of driving for all gasoline-powered vehicles. Higher gasoline prices, however, increases the cost per mile more for vehicles with low fuel economy than for vehicles with high fuel economy. Therefore, the fuel costs of vehicles with low fuel economy increases relative to the fuel costs of vehicles with high fuel economy. This increase in relative fuel costs causes willingness to pay for vehicles with high fuel economy to rise and the willingness to pay for vehicles with low fuel economy to fall.

Our empirical strategy aims to recover the equilibrium relationship between vehicle registrations and fuel costs. This equilibrium relationship incorporates all possible supply adjustments – such as changes in vehicle prices. Therefore, the coefficients of interest are interpreted as the effect of fuel cost changes on equilibrium registrations.[20]

Equation (1) is not a demand model since it is not derived from underlying structural assumptions about buyer preferences. Instead, it is assembled to estimate reduced-form relationships between vehicle registrations and fuel costs for each buyer type. The coefficient estimates, however, do reveal information about the demand for fuel economy, since the reduced form relationships are identified from shifts in demand curves and movements along supply curves. Throughout the text we denote this information as "demand for fuel economy" or "demand for fuel costs" although we are not estimating demand model coefficients or willingness to pay for fuel economy.

4 Estimation Results and Implications

4.1 Comparing Fleet and Household Responses

Table 3 reports the main regression results for coefficient β_r in Equation (1). The dependent variable is the log of vehicle registrations by vehicle stub, month, and buyer type. We estimate Equation (1) using panel data from Q3 2009 to Q4 2016 by ordinary least squares. Our regressions include quarterly fixed effects as well as the interacted term of vehicle stub (including model year) by market year fixed effects. These independent variables control for demand and supply unobservables for each product (vehicle stub) over market years as well as unobservable quarterly shocks that are constant across products. In column 1, we estimate Equation (1) using the sample for all retail registrations by households from Q3 2009 to Q4 2016. In column 2, we estimate the same equation using all fleet registrations from Q3 2009 to Q4 2016. Our retail regression in column 1 includes more observations than

[20] A referee suggested that one could control for transaction price changes by collecting price discount or promotional data. This type of analysis requires transaction price data for fleet vehicle sales. Although transaction prices of vehicles bought by households are available, we are unaware of such a dataset for the fleet buyers.

our fleet regressions in column 2 because individual households purchased more distinct vehicle stubs than did fleet buyers during our sample period.

Column 1 shows the point estimates for fuel cost (dollars per mile) is -7.39 and significant at the 1 percent level.[21] To interpret this coefficient, we consider a typical Honda Accord model year 2016 (30 mpg) and a typical Ford F-150 model year 2016 (18 mpg). Our estimate implies that a hypothetical one dollar increase in all fuel prices would increase retail registrations for Accords by about 16.4 percent, compared with the retail registrations of Ford F-150s. The magnitude of our estimate is comparable to previous studies that estimate demand response to fuel price changes for retail markets.[22]

We report the point estimate for fleet registrations in column 2. Our estimate for the effect of fuel cost is -5.91 and it is significant at the 1 percent level. Using the same example of a Honda Accord and a Ford F-150 as above, our point estimate for fleet registrations implies that a hypothetical one dollar increase in all fuel prices would raise fleet registrations for Accords by about 13.1 percent, compared with fleet registrations of Ford F-150s. Despite potential reasons that may hold fleet buyers back from accounting for fuel cost savings when making a purchase discussed in Table 1, we find on average fleet buyers do respond to fuel price changes. In the next section 4.2, we explore further how different subgroups of fleet buyers respond to fuel price changes.

Comparing column 1 and column 2, we find the magnitude of the retail and fleet coefficients are not distinguishable since their confidence intervals appear to overlap. To formally test this hypothesis, we estimate the combined sample and test whether the interaction term defined as the product of fuel costs and a dummy variable for fleet registrations is different from zero. To be comparable to Table 3, we further interact quarterly fixed effects and the interaction term of vehicle stub (including model year) and market year with the fleet dummy.

Table 5 reports these estimates. The coefficient for retail registrations is -7.39, significant at 1 percent level. The coefficient of the interaction of the fleet dummy and fuel costs is 1.48 with standard error 2.47, insignificant at the 10 percent level. We cannot reject the hypothesis that fleet and retail vehicle registrations respond to fuel price changes in similar ways. While our results cannot reject the hypothesis that household and fleet buyers respond similarly to gas price changes, we also do not have the power to reject that they behave quite differently.

[21] We cluster standard errors at vehicle trim level. There are 463 models and 1,645 trims in our data. See Appendix Table B.2 for more conservative standard errors using robust standard errors clustered at vehicle model level. Our results are robust to alternative standard errors.

[22] Leard et al. (2017a) find a comparable estimate of -6.80 using monthly sales data from 2008 to 2015.

Table 7 further investigates whether the pattern of responses to fuel price changes vary over time. As shown in Figure 4, gasoline prices have had several periods of low volatility and several periods of high volatility. To allow the effect of fuel price changes on vehicle registrations to vary over time, we break down the eight years of the sample into four periods: Q3 2009 to Q4 2010, 2011 to 2012, 2013 to 2014, and 2015 to 2016. In both panels, column 1 repeats the baseline for convenience. In column 2, we interact fuel costs (dollars per mile) with the set of time period dummies defined above. We find that for both household buyers and fleet buyers, responsiveness to fuel price variation is similar over time from 2009 to 2016.[23]

The estimates have important implications for the vehicle demand literature and studies on fuel consumption policies. Previous studies have implicitly assumed that new vehicle buyers responsiveness to fuel price changes are identical in both retail and fleet markets. Our results imply that this assumption is statistically valid, at least for the period considered here.

4.2 Comparing Rental, Commercial, and Government Responses

In this section, we examine the fleet market in greater detail in 2015 and 2016, and observe disaggregated fleet registrations by three types: rental companies, commercial companies, and government units. We estimate Equation (1) separately for each group of fleet buyers and retail buyers using quarterly data from Q1 2015 to Q4 2016.

We begin with re-estimating our benchmark equation with data restricted to this time period, where coefficient estimates appear in Table 4. In column 1, we show that the point estimate for household buyers in the retail market is -8.49 and is significant at the 1 percent level. This magnitude is comparable to our baseline estimate, obtained using the data from 2009 to 2016 shown in Table 3. Column 2 of Table 4 shows that our point estimate for all fleet buyers is also comparable to our baseline as well.

Column 3 reports that the point estimates for rental companies from 2015 to 2016 is -14.52 and significant at the 1 percent level, suggesting that rental companies are sensitive to fuel price changes. Using the same example as in Section 4.1 to interpret Table 4, column 3 suggests that a hypothetical one dollar increase in all fuel prices would increase the retail registrations of Honda Accords by 18.9 percent relative to Ford F-150s, and would increase the rental company registrations of Honda Accords by 32.3 percent relative to Ford F-150s.

[23] In addition, we find that the purchase responses are similar across fuel economy groups as shown in Appendix Table B.1.

We show results for commercial companies and government units in Table 4 columns 4 and 5. The results suggest that commercial companies are insensitive to fuel price changes, with a coefficient of -2.4. But this coefficient is significant at only the 10 percent level. The coefficient on government purchases is of the right sign and small, but not significant. These results for commercial and government buyers are consistent with reasons discussed in Table 1. They tend to have more specialized vehicles needs than household buyers, and are thus likely to be less responsive to fuel cost changes.

Overall, these results suggest that the largest buyer in the fleet vehicle market, car rental companies which represent about 80 percent of registrations, respond to fuel price changes. This implies that the features causing rental car companies to be insensitive to fuel price changes such as "dumping " by the automobile companies as described in Table 1, are dominated by other incentives that cause them to respond to fuel cost changes such as "selling on the used car market." These results also imply that the reasons we hypothesize for commercial companies and government buyers are present in the data: they barely respond to fuel price changes for reasons we discussed in Table 1.

Because Table 4 suggests only household buyers and rental car companies respond to fuel price changes in 2015 and 2016, we proceed to test whether rental car companies responses are similar to that of household buyers. We test this hypothesis and show results in column 2 of in Table 5. We include fuel cost interacted with all buyer types using a combined sample of all buyers from 2015 to 2016. We further interact quarterly fixed effects with buyer type fixed effects, and the interaction of vehicle stub (including model year) and market year further with buyer type fixed effects, to be comparable to Table 4.[24] Column 2 shows that our key parameter for the retail market is still -8.49 and significant. We focus on the interaction of fuel costs with a rental company dummy to test our hypothesis. The coefficient for the interaction with rental car company is -6.03, but it is not precisely estimated. Thus, while we cannot reject that rental companies and household buyers behave similarly, we also cannot reject that they behave quite differently.

We find these results on the responsiveness of different fleet buyers to changes in fuel prices to be suggestive at this point. The limited data do not allow us to estimate these effects with much precision. The result that the coefficient on the rental car fleet could be higher than for the retail market is important to explore because the rental car fleet is such a large share of the total light-duty fleet. On the other hand, rental car registrations have been declining in recent years, possibly because of the growing popularity of ride sharing

[24]Because of the high dimension of the interaction terms, our combined sample from 2015 to 2016 experiences a reduction in sample size compared with that in Table 4.

services. Ride sharing miles and their response to fuel price changes will be important to explore in future work.

4.3 Implications for Fuel Consumption Policies and Their Effect on Vehicle Fuel Economy

We have demonstrated in Section 4.1 that fleet buyers and retail buyers as a whole are not distinguishably different in how they respond to fuel price changes. This result implies that a hypothetical increase in the federal gasoline tax (or the imposition of a federal carbon tax) would have a similar effect, on average, for both markets.

However, retail and fleet categories have a different mix of sizes and types of vehicles as shown in Figure 2. For example, vehicles purchased by government units not only have a relatively narrow range of fuel economy, but the distribution is also more concentrated around the mean. Therefore, although a hypothetical increase in the federal gasoline tax (or other fuel consumption policies) may have a similar average effect on different buyers, it is not clear whether the distributional effects across vehicles would be comparable as well. Furthermore, given that we have found that the unique types of fleet buyers have different responses to fuel price changes, policies influencing fuel prices are likely to have substantially different effects for these buyers.

We begin by analyzing how a higher gasoline price affects mean fuel economy as well as the distribution of sales cross vehicle types. We simulate the effects of a one dollar increase in the federal gasoline tax in 2015, assuming that the tax increase is completely passed through to retail gasoline markets. This simulation is equivalent to raising the price of gasoline from \$2.25 per gallon to \$3.25 per gallon (all figures are in 2010 USD). To put this simulation in perspective, a gasoline price of \$3.25 per gallon is similar to the average retail gasoline price in 2013, which was \$3.29 per gallon.

To simulate the effect of this hypothetical change, we use the baseline coefficients β_r estimated from 2009 to 2016 in Table 3 panel A. We report simulation outcomes in Table 6. The first column of Table 6 reports simulation results for the retail market, and the second column reports simulation results for the fleet market. Our analysis suggests that a one dollar increase in gasoline prices would cause the average fuel economy in 2015 to increase by 0.39 miles per gallon (equivalent to 1.7 percent of average fuel economy) for vehicles bought by households, and 0.33 miles per gallon (equivalent to 1.5 percent of average fuel economy) for fleet vehicles. The similarity in magnitude suggests that increasing the federal gasoline tax would have a similar modest effect on the two markets in the short run.

We further break down the effect for the four buyer types in panel B of Table 6, using coefficients estimated from 2015 to 2016 in Table 4. These estimates show substantial heterogeneity in the fuel economy response to increasing gasoline prices: fuel economy of rental car company vehicles increases by about 0.69 miles per gallon (equivalent to 2.9 percent of average fuel economy), while commercial and government vehicle fuel economy barely changes.

In the appendix, we show that the sales mix effects broken down by body type and find that increasing gasoline prices shift registrations away from pickup trucks and SUVs to more fuel efficient sedans and hatchbacks in both markets. The shift away from SUVs is relatively larger in the rental car market since baseline SUV registrations are higher relative to baseline rental pickup truck registrations.[25]

A limitation of our approach is that our estimates are based on gasoline price variation as opposed to gasoline or carbon tax variation. Recent literature has found that gasoline consumption has a larger response to gasoline tax changes than it does to tax-exclusive gasoline price changes (Li et al. 2014; Rivers and Schaufele 2015), and some evidence suggests that the demand for fuel economy may also respond more to gasoline tax changes (Li et al. 2014). In our analysis, it would be interesting to explore whether fleet and retail buyers respond differently to gasoline tax changes compared to market price changes. Unfortunately, our data do not permit addressing this question because we do not observe significant changes in average national gasoline taxes during the sample period.[26]

4.4 Robustness Checks

In this section, we demonstrate that our conclusion that household and fleet buyers respond similarly to fuel price changes is robust to addressing potential sources of bias and alternative assumptions.

We consider potential unobservable demand shocks specific to vehicle class varying over time. Such shocks can bias our estimates if they are correlated with fuel costs after we control for extensive sets of fixed effects. For example, Volkswagen diesel engines were revealed to be not compliant with EPA emissions standard on September 18, 2015. Because diesel engines are more often used in light trucks, this shock can affect light trucks more than passenger cars in subsequent quarters. To account for such potential shocks, we further control for a truck dummy interacted with a linear quarter trend in Table B.3 column 3. In addition, we define vehicle class using body style variables (sedan, convertible, coupe, hatchback, station wagon,

[25] See Figures A.3 and A.4 for a breakout of changes in registrations by vehicle class and buyer type.

[26] As pointed out by a referee, this question requires a long panel of state-level variation in gasoline taxes as used in (Li et al. 2014). Therefore, we leave this question for future research.

SUV, van, cab and chassis, pickups, and truck). We further control for class interacted with a linear quarter trend. Our results are robust to including this additional control variable (not reported). We find results comparable to our baseline, and no significant differences between retail and fleet coefficients.

In the appendix, we report further robustness including adding linear quarter trends and testing whether fuel price changes have persistent effects. Our results are broadly robust to these tests.[27] Our results are also robust to alternative definition of vehicle stub (see Table B.4) or when restricting to overlapping vehicles that both household and fleet buyers purchase from.[28]

Although the results show that both fleet and retail buyers have a similar response to contemporaneous fuel cost changes, they may respond differently to persistent price changes. We address this possibility by including quarterly leads and lags in the benchmark specification and report the estimation results in Appendix Table B.5. The results show that both buyer types have similar responses to persistent changes in fuel costs. Moreover, our results are robust to vehicles with different measures durability using lifetime vehicle miles traveled, as well as other measures that can infer vehicles with different durability (such as segment, foreign dummy, and price range).

Lastly, our estimates do not represent structural demand parameters but instead indicate equilibrium quantity responses to fuel price changes. An alternative approach would be to estimate separate structural demand models for fleet and household buyers and compare their price fuel cost coefficient estimates. We have decided to take a reduced-form approach to exploit plausibly exogenous variation in fuel costs stemming from changes in gasoline prices.[29]

5 Conclusion

Understanding how policies affect fuel consumption and greenhouse gas emissions from the transportation sector is crucial given the large social welfare effects caused by these policies. A key determinant of the efficacy of fuel consumption policies is how vehicle

[27] See Table B.3 for the results with a linear quarter trend added and Table B.5 for the results with lagged fuel costs.

[28] Contact authors for additional results.

[29] In related work, we have estimated separate structural demand models for fleet and household buyers using variation suggested by Berry et al. (1995). For this identification strategy, we instrument for vehicle prices using characteristics of other vehicles sold by the same manufacturer and characteristics of vehicles sold by different manufacturers, and we assume that fuel costs are exogenous. Our results are broadly similar to those in the current paper in that fleet and household fuel cost coefficients are similar in magnitude. Contact the authors for these results.

demand responds to fuel cost changes. Using a unique dataset of new vehicle registrations by buyer type from 2009 to 2016, in this paper we estimate the effect of fuel price changes on new passenger vehicle registrations for previously ignored groups of fleet buyers: rental car companies, commercial buyers, and governments. We find a precise relationship between fuel price changes and new vehicle registrations for fleet buyers. Moreover, we further find that this effect is of similar magnitude for fleet buyers as it is for household buyers in the retail market. In particular, we can not reject the hypothesis that fuel price changes have similar effects on new vehicle registrations for the two types of buyers. Our results suggest that increasing gasoline taxes would affect household demand and fleet demand for fuel economy by a similar magnitude. Analyses calibrating demand responses to fuel cost changes using household level data may be an accurate representation of the entire light-duty new vehicle market. Our findings defend generalizing policy analysis results derived from household data – which is, to the best of our knowledge, the only form of available micro data on vehicle purchases and holdings – to the entire light-duty vehicle market.

Similar to the findings reported in Leard et al. (2017a), we find that fuel price changes have a modest effect on market-wide new vehicle fuel economy: a one-dollar increase in gasoline prices causes an increase in average new vehicle fuel economy by about 0.3 to 0.4 miles per gallon. This responsiveness is much lower than earlier time periods and suggests that policies that increase fuel prices - namely gasoline taxes - have a limited impact on raising new vehicle fuel economy.[30]

The results of our analysis for the different types of fleet demand – rental, commercial and government – show differences in their response to fuel price changes, where commercial and government buyers appear unresponsive. This lack of response could be caused by current regulations that require these buyers to purchase certain types of vehicles, motivating a closer analysis of these regulations in future work.

There are several caveats to our analysis. First, our identification strategy exploits quarterly variation in fuel prices. Therefore, our results should be interpreted as short-run responses. Whether household and fleet buyers respond differently to long periods of low gasoline prices is is left for future research. Second, we estimate the effect of fuel price changes on equilibrium registrations. We then make comparisons of these effects among the buyer types. Without a detailed supply side model, we cannot make a strong claim about differences in demand because manufacturer pricing responses may be unique to each buyer type. This suggests a need to analyze how vehicle prices faced by each buyer type respond

[30] A similar conclusion could be drawn regarding the effects of a carbon tax, with the exception that a carbon tax would impact many other components of new vehicles besides fuel costs and therefore may have a stronger effect on fuel economy demand.

to fuel price changes. We do not focus on the demand for other vehicle attributes such as performance, size, or safety, which have implications for assessing the welfare effects of fuel economy standards and other related policies (Jacobsen 2013b, Bento et al. 2017, Leard et al. 2017b, Whitefoot et al. 2013). Another limitation of our approach is that we are unable to estimate the effect of gasoline price changes on total new vehicle sales. This effect is relevant for understanding both how fuel cost changes translate to total greenhouse gas emissions from the transportation sector and how fuel price changes affect substitution from new vehicles to other travel alternatives (such as used car).[31] Lastly, evaluating the welfare implications of fuel consumption policies requires making assumptions about vehicle miles traveled (VMT) and scrappage decisions in addition to vehicle purchase decisions. VMT and scrappage rates of fleet vehicles may respond differently to fuel price changes than household vehicles, motivating future work to disaggregate these decisions by vehicle ownership type.

[31]Our estimation equations include fixed effects that control for all macroeconomic shocks that can impact total sales by buyer type, and we are unable to disentangle the effect of gasoline price shocks from other macroeconomic shocks. Furthermore, the limited number of time periods in our sample provides insufficient variation in macroeconomic shocks to disentangle the effect of gasoline price changes from other factors such as unemployment. A longer time series (e.g., 20 or more years) with multiple periods of large changes in gasoline prices would be necessary to precisely estimate the total sales effect.

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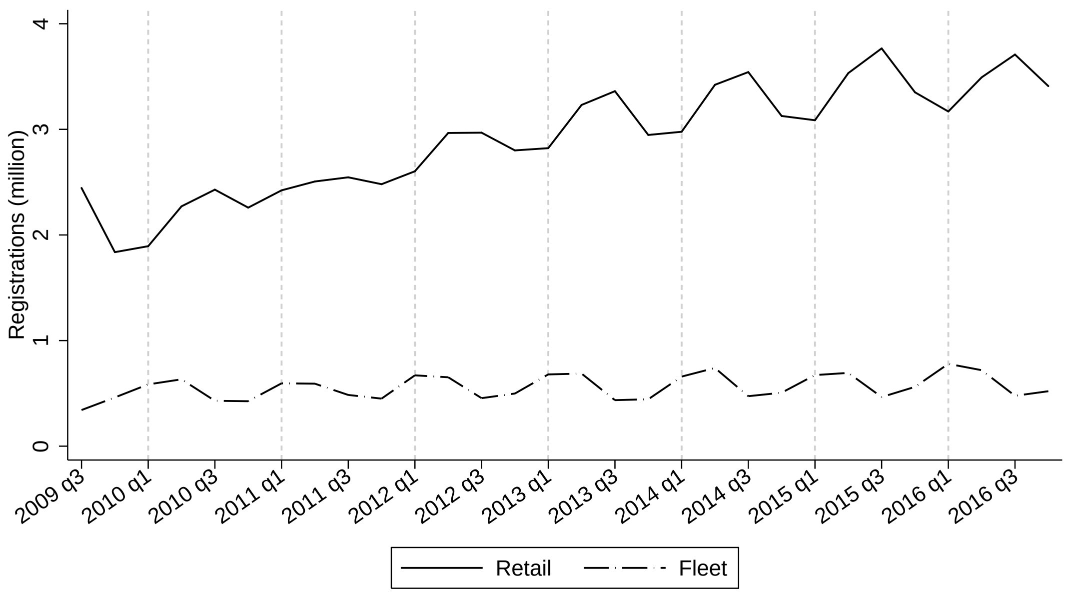
Figures

Figure 1: **Vehicle Registrations by Buyer Type, 2010–2016**

Panel A. Vehicle registrations by household buyers in the retail market and fleet buyers



Panel B. Vehicle registrations by sub-groups of fleet buyers

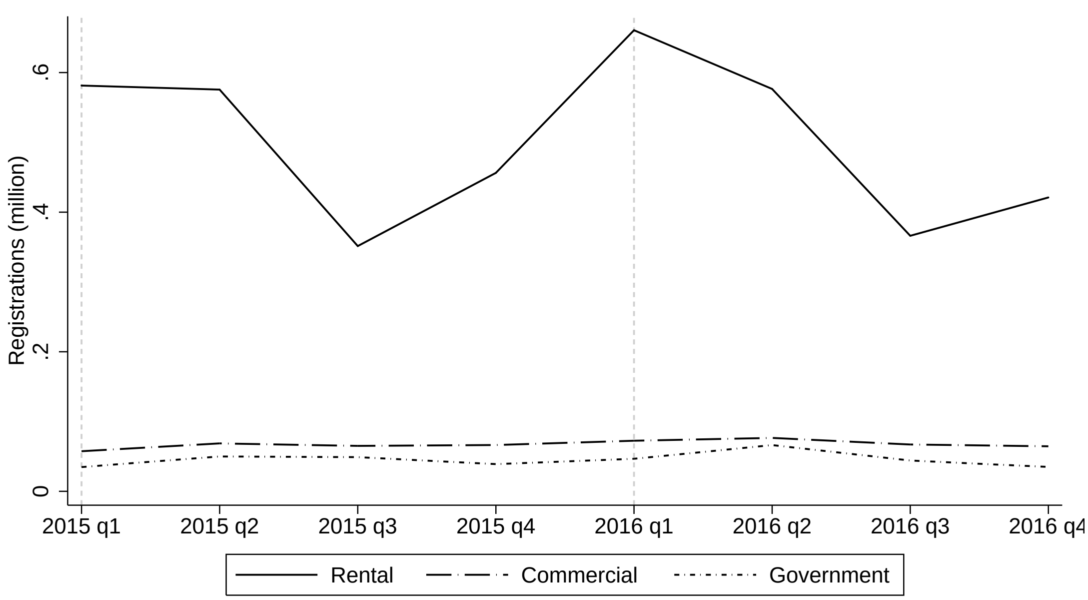
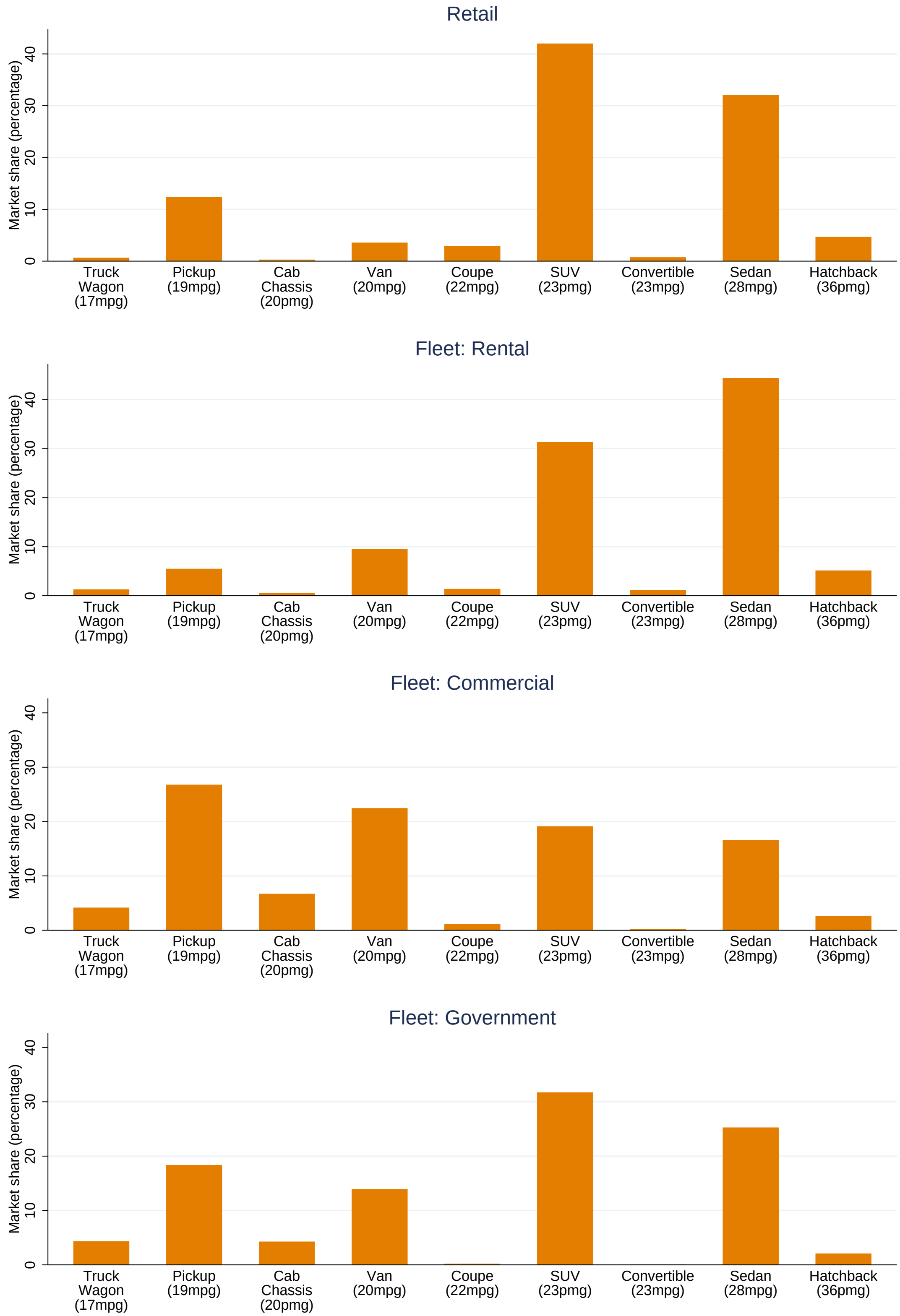


Figure 2: **Body Style Distribution by Buyer Type, 2015–2016**



Notes: For each figure, we plot market share of each body style for different types of buyer. For each body style in parentheses we report the national fleet average of fuel economy ratings in 2015.

Figure 3: **Domestic and Foreign Vehicles by Buyer Type, 2015–2016**

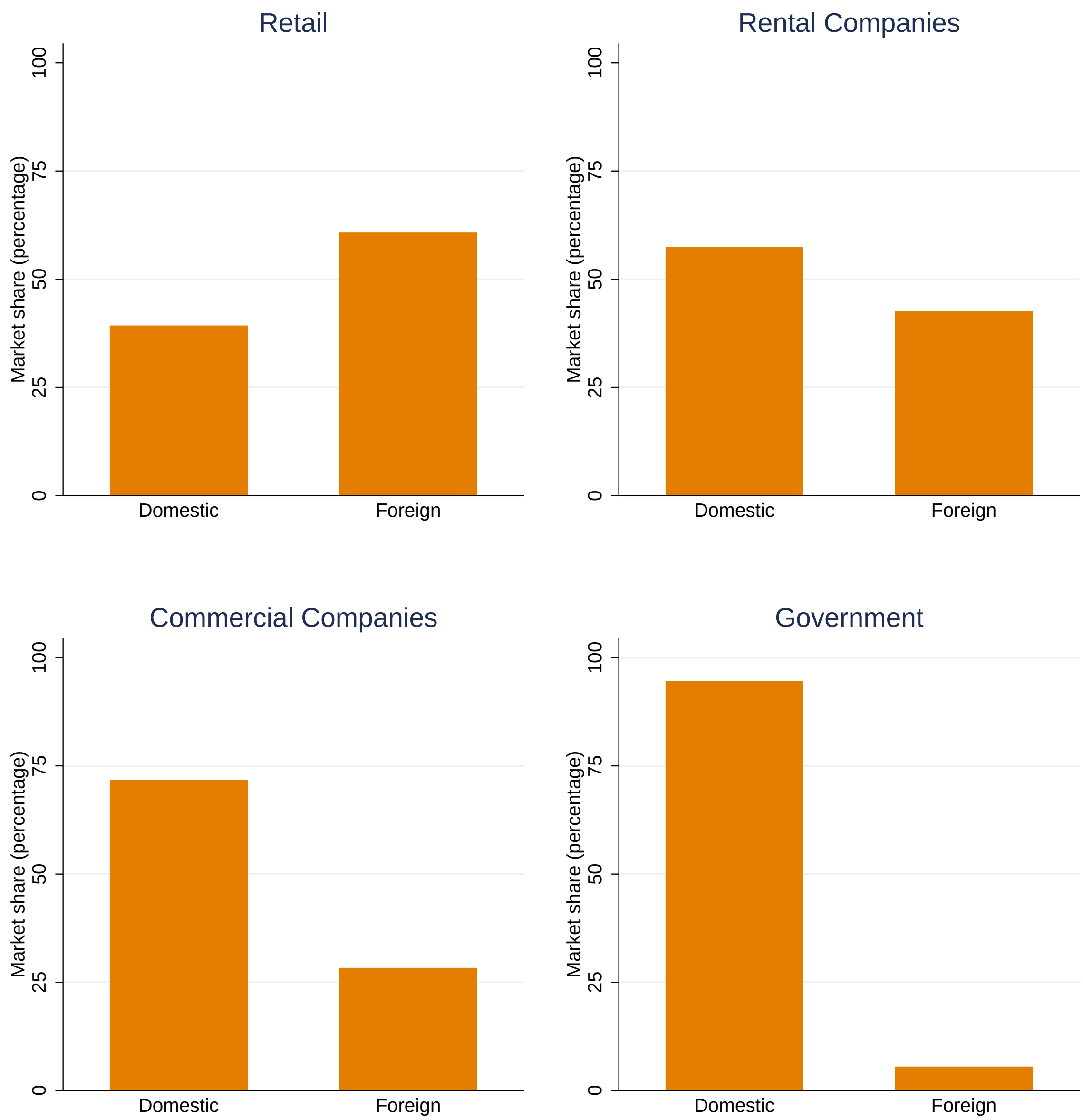
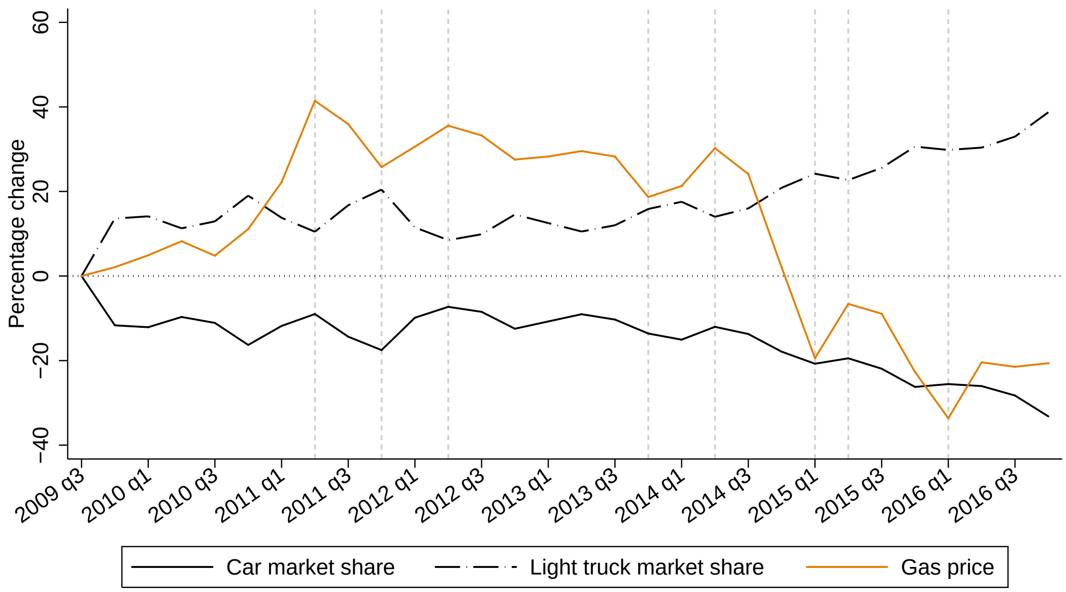


Figure 4: **Changes in Market Share of Cars versus Light Trucks and Gasoline Prices, 2010–2016**

Panel A. Retail registrations by households



Panel B. Fleet registrations

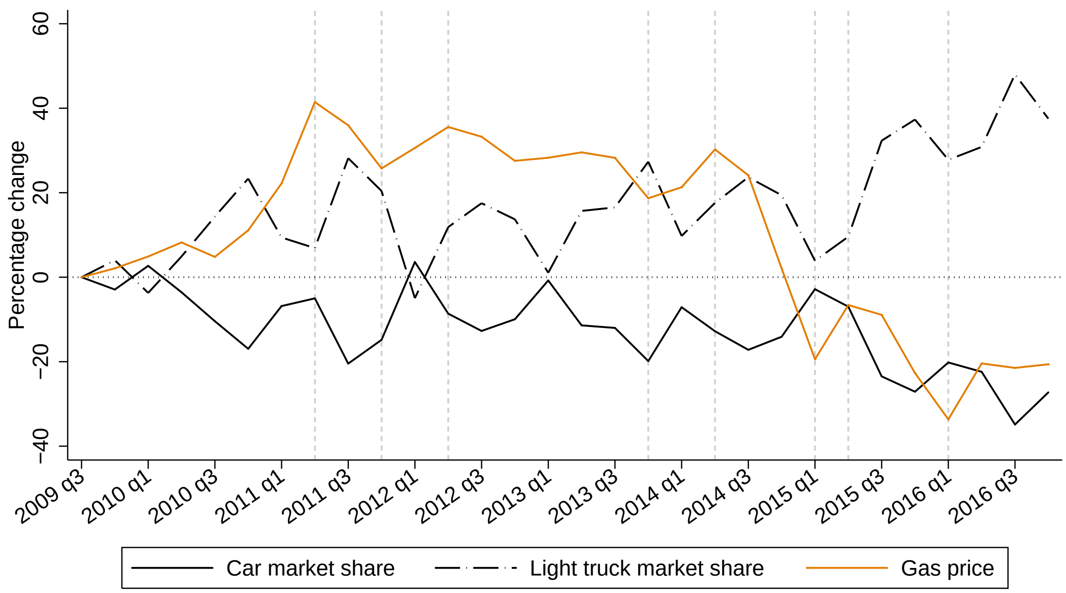
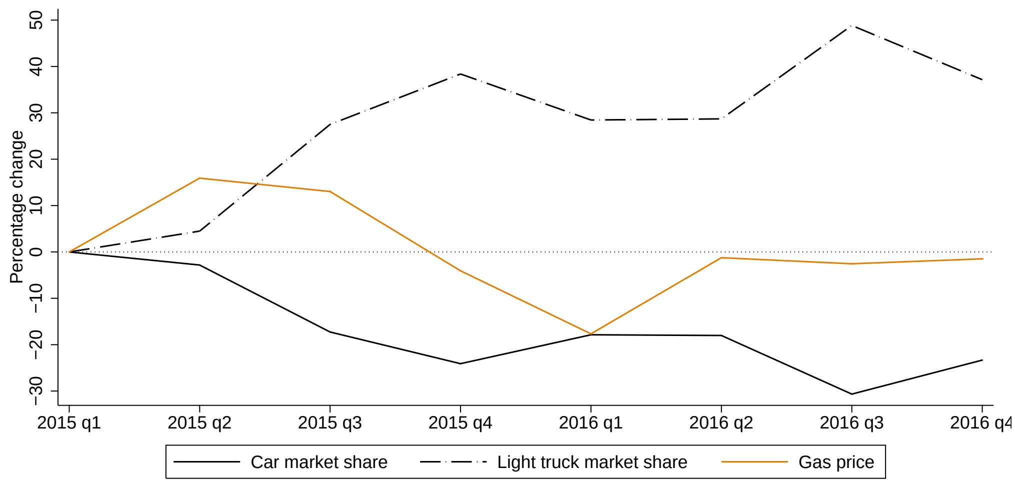
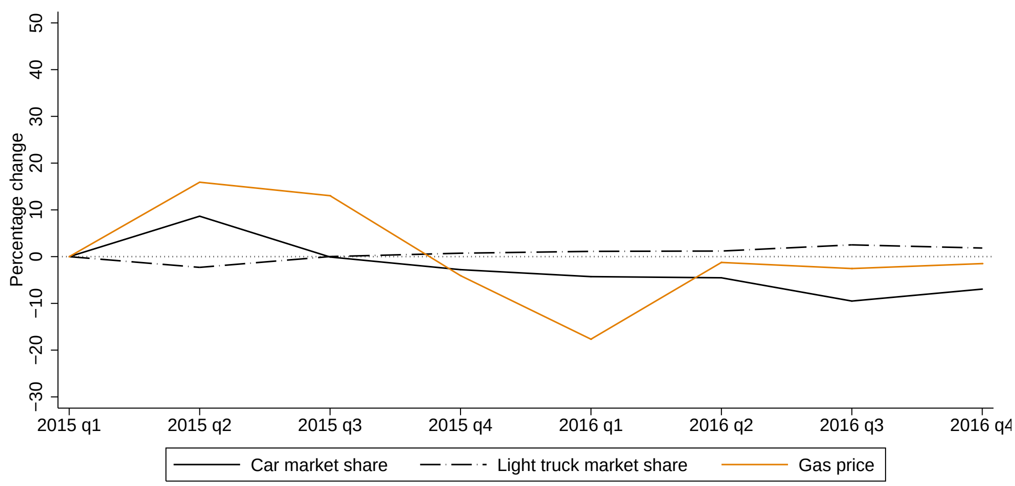


Figure 5: **Changes in Market Share of Cars versus Light Trucks and Gasoline Prices by Fleet Subgroups, 2015–2016**

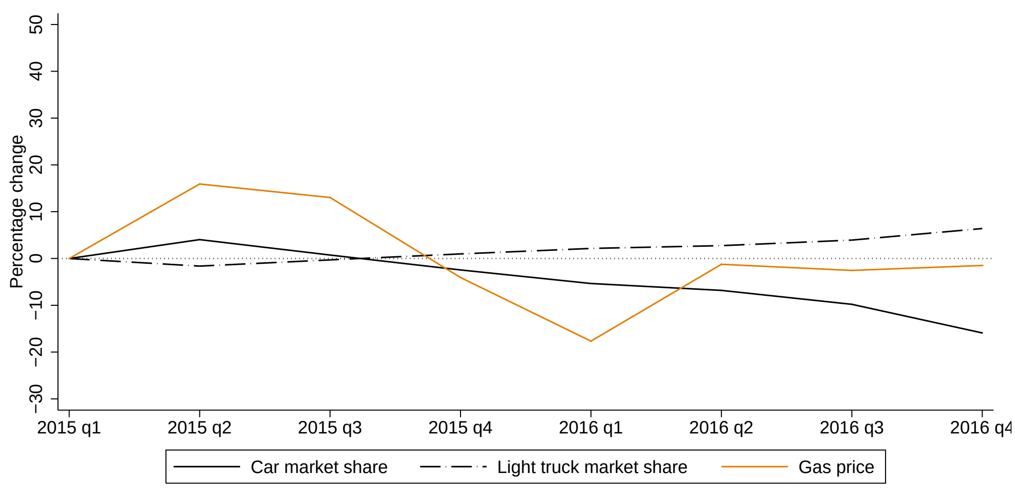
Panel A. Rental Companies



Panel B. Commercial Companies



Panel C. Government



Tables

Table 1: **Distinguishing Features of Fleet Demand**

Feature	Type of fleet	Explanation
Different vehicle uses	commercial, government	Many government and commercial fleet vehicles have specific uses and requirements that do not involve transporting passengers.
Vehicle miles traveled schedules	rental, commercial, government	Vehicles expected vehicle miles traveled schedules differ depending on their class (e.g., car vs. pickup truck) and their use.
Subsidy incentives	government	Federal government policies and subsidies such as "buy American" may incentivize government agencies to respond less to fuel price changes (Li et al. 2015).
Regulatory requirements	government	Regulatory requirements may limit the set of vehicles that government buyers choose from. For example, the Executive Order 13693 requires any federal fleet with 20 or more vehicles to cut per-mile pollution from fleets by 30 percent from 2014 levels by 2025 and to increase purchases of all-electric and plug-in hybrid vehicles to 20 percent of new acquisitions by 2020 and 50 percent by 2025.
Principal-agent problem	government	If the decisions about fuel economy are removed from budget considerations by the overseeing government agency, then fuel savings will not be fully considered by fleet buyers (Arrow 1985; Graus and Worrell 2008; Adland et al. 2017).
Rental length	rental car	Vehicle renters may not be sensitive to fuel economy or fuel costs because rental periods are typically short, lasting only a few days. This contrasts with household buyers that typically hold the vehicle for 3–5 years before selling.
Dumping incentives	rental car	Automobile manufacturers may have incentives to sell or "dump" vehicles in low demand to rental car companies.
Contract buyback options	rental car	Rental companies have buy-back options in contracts with automobile manufacturers for some vehicles, and may therefore be less responsive to fuel price changes.
Selling on the used vehicle market	rental car	Rental companies sell vehicles after 12–18 months of use, and used vehicle sales are a key source of revenue. This contrasts with household buyers that tend to keep newly purchased vehicles for 3-5 years before selling.

Notes: Each row represents a possible reason why fleet demand for fuel economy may respond differently to fuel price changes than household demand. The dumping incentives and contract buyback options were suggested to us by a representative of a major automobile manufacturer.

Table 2: **Summary Statistics by Time Period**

	2009–2010	2011–2012	2013–2014	2015–2016
Panel A. Retail Market for Household Buyers				
Quarterly registrations	1,324	1,316	1,447	1,623
	(3,915)	(3,972)	(4,774)	(5,366)
Gasoline price (2010 USD per gallon)	2.75	3.43	3.19	2.11
	(0.10)	(0.15)	(0.23)	(0.20)
Fuel economy (miles per gallon)	22.3	23.9	25.3	25.4
	(5.7)	(6.0)	(7.9)	(7.9)
Fuel cost (dollars per mile)	0.13	0.15	0.13	0.09
	(0.03)	(0.03)	(0.03)	(0.02)
Horsepower	216	222	226	234
	(69)	(76)	(81)	(84)
Weight (lbs)	3,739	3,743	3,781	3,847
	(807)	(798)	(796)	(768)
Truck	0.51	0.52	0.53	0.60
Panel B. Fleet Market				
Quarterly registrations	400	412	397	213
	(1,438)	(1,540)	(1,518)	(1,127)
Gasoline price (2010 USD per gallon)	2.75	3.43	3.19	2.11
	(0.10)	(0.15)	(0.23)	(0.20)
Fuel economy (miles per gallon)	22.2	22.9	24.1	24.3
	(4.9)	(5.2)	(6.1)	(6.0)
Fuel cost (dollars per mile)	0.13	0.16	0.14	0.09
	(0.03)	(0.04)	(0.04)	(0.02)
Horsepower	205	223	229	235
	(61)	(77)	(84)	(88)
Weight (lbs)	3,781	3,857	3,905	3,892
	(871)	(872)	(904)	(863)
Truck	0.45	0.47	0.49	0.53
Number models				463
Number of trims				1,645
Number of stubs				3,929

Notes: Each column represents means and standard deviations of vehicle characteristics for two-year periods in our sample. Vehicle characteristics are weighted by the number of registration. Standard deviations are reported in parentheses. Rows in Panel A report statistics for household buyers only. Rows in Panel B report statistics for fleet buyers only.

Table 3: **Effect of Fuel Cost Changes on Retail and Fleet Registrations, 2009–2016**

Dependent variable: log registrations	(1) Retail	(2) Fleet
fuel cost (dollars per mile)	-7.391***	-5.911***
	(1.801)	(2.010)
Number of observations	77,874	67,923
R-squared	0.88	0.75
* p<0.10 ** p<0.05 *** p<0.01		

Notes: Robust standard errors clustered by vehicle trim included in parentheses. This table reports the baseline results of estimating Equation 1 by ordinary least squares. The dependent variable is log of number of registrations by vehicle stub, buyer type (retail or fleet) and quarter in each calendar year. All specifications include quarter fixed effects. All specifications also include vehicle stub (including model year) by market year fixed effects. A vehicle stub is defined by a unique combination of a unique model year, vehicle model name in IHS, series name in IHS, fuel type, body type, drive type, and liters of displacement. A market year is defined from the fourth quarter of previous year to the third quarter of current year. Column 1 reports retail results and column 2 reports the fleet results. (See Appendix Table B.2 for a more conservative standard error using clustered at vehicle model level.)

Table 4: **Effect of Fuel Cost Changes on Detailed Fleet Registrations, 2015–2016**

Dependent variable: log registrations	(1)	(2)	(3)	(4)	(5)
Buyer types in samples:	retail	fleet all	fleet rental	fleet commercial	fleet government
fuel cost (dollars per mile)	-8.488***	-5.185**	-14.516***	-2.449	-1.535
	(2.063)	(2.440)	(4.034)	(2.580)	(4.294)
Number of observations	22,963	33,738	9,445	11,093	5,150
R-squared	0.89	0.59	0.84	0.86	0.85
* p<0.10 ** p<0.05 *** p<0.01					

Notes: Robust standard errors clustered by vehicle trim included in parentheses. This table reports the baseline results of estimating Equation 1 by ordinary least squares in a reduced sample from 2015 to 2016. The dependent variable is log of number of registrations by vehicle stub, buyer type (retail or fleet) and quarter in each calendar year. All specifications include quarter fixed effects. All specifications also include vehicle stub (including model year) by market year fixed effects. Column 1 reports retail results, column 2 estimates for all fleet registration, and column 3 – 5 reports results for a subsample of rental companies, commercial companies, and government buyers. (See Appendix Table B.2 for a more conservative standard error clustered at vehicle model level.)

Table 5: **Testing Whether Different Buyer Types Have the Same Effects of Fuel Cost Changes on New Vehicle Registrations**

Dependent variable: log registrations	(1) Test baseline retail vs. fleet 2009 – 2016	(2) Test retail vs. fleet subgroups 2015 – 2016
fuel cost (dollars per mile)	-7.391***	-8.488***
	(1.801)	(2.063)
fuel cost × fleet	1.480	
	(2.192)	
fuel cost × fleet (rental or leasing companies)		-6.028
		(4.145)
fuel cost × fleet (commercial companies)		6.039**
		(2.935)
fuel cost × fleet (government agencies)		6.952
		(4.554)
Equivalent to	Table 3	Table 4
Number of observations	145,797	48,651
R-squared	0.85	0.90

* p<0.10 ** p<0.05 *** p<0.01

Notes: Robust standard errors clustered by vehicle trim included in parentheses. Column 1 tests if parameter β_r in 3 are identical. Column 1 estimates in a combined sample for all buyer types (retail and fleet) from 2009 to 2016. To be comparable to Table 3, we further interact quarter fixed effects interacted with the fleet dummy, and vehicle stub (including model year) by market year with the fleet dummy. Column 2 tests if parameters β_r in 4 are identical. Column 2 estimates in a combined sample for all buyer types (retail, rental and leasing companies, commercial companies, and government agencies) from 2015 to 2016. To be comparable to Table 4, we interact quarter fixed effects with detailed fleet subgroup fixed effects (4 groups), and vehicle stub by model year by market year with detailed fleet subgroup fixed effects (4 groups). By including these interactions, we lose some observations compared to specifications in Table 4.

Table 6: **Simulated Effect of a One Dollar Gasoline Price Increase on Average Fuel Economy by Buyer Type, 2015**

	(1)	(2)	(3)	(4)	(5)
Buyer type:	Retail	Fleet	Rental	Commercial	Government
Panel A. Average fuel economy (miles per gallon) in 2015					
(Using Coefficients from Table 3 on Sample from 2009 to 2016)					
Predicted average	23.75	21.38			
	[23.26, 24.25]	[20.91, 21.88]			
Counterfactual average	24.12	21.68			
	[23.89, 24.36]	[21.68, 21.89]			
Change	0.37	0.33			
	[0.11, 0.63]	[0.01, 0.53]			
Change (percentage)	1.6%	1.5%			
	[0.5%, 2.7%]	[0.05%, 2.5%]			
Coefficient for fuel cost	-7.39	-5.91			
Num. of obs. in 2015	12,786	16,754			
Panel B. Average fuel economy (miles per gallon) in 2015					
(Using Coefficients from Table 4 on Sub-sample in 2015 and 2016)					
Predicted average	23.81	21.31	23.73	20.74	20.39
	[23.29, 24.34]	[20.78, 21.91]	[22.82, 24.66]	[20.17, 21.20]	[19.75, 21.14]
Counterfactual average	24.24	21.55	24.43	20.83	20.46
	[24.00, 24.49]	[21.30, 21.82]	[24.02, 24.84]	[20.52, 20.98]	[20.12, 20.71]
Change	0.43	0.24	0.70	0.09	0.07
	[0.15, 0.71]	[-0.09, 0.52]	[0.18, 1.2]	[-0.22, 0.35]	[-0.43, 0.37]
Change (percentage)	1.8%	1.1%	2.9%	0.4%	0.3%
	[0.6%, 3.0%]	[-0.04%, 2.4%]	[0.8%, 5.1%]	[-0.01%, 1.7%]	[-2.1%, 1.8%]
Coefficient for fuel cost	-8.49	-5.19	-14.52	-2.449	-1.535
Num. of obs. in 2015	12,786	16,754	5,076	6,022	2,784

Notes: Confidence intervals in square parentheses. In Panel A, we report the simulated effects of a one dollar increase in the price of gasoline in 2015 using the baseline coefficient estimates from columns (1) and (2) in Table 3, which disaggregate registration responses to fuel price changes by household and fleet buyers. The row labeled change represents the simulated change in average fuel economy of new vehicle registrations. In Panel B, we report the simulated effects of a one dollar increase in the price of gasoline in 2015 using the coefficient estimates from columns (1), (3), (4), and (5) in Table 4, which are based on the responses disaggregated for rental car, commercial, and government buyers. Average fuel economy is harmonic fuel economy weighted by the number of registrations. In row B.1, fuel economy is weighted using the simulated number of registrations. In row B.2, fuel economy is weighted using the simulated number of registrations. We report the changes from predicted average fuel economy to counterfactual fuel economy in row B.3.

Table 7: **Effect of Fuel Cost Changes on New Vehicle Registrations by Time Period, 2009–2016**

Dependent variable: log registrations	A. Retail		B. Fleet	
	(1)	(2)	(1)	(2)
	Baseline		Baseline	
fuel cost (dollars per mile)	-7.391***		-5.911***	
	(1.801)		(2.010)	
fuel cost× 2009–2010		-7.116***		-6.803***
		(2.281)		(2.631)
fuel cost× 2011–2012		-7.442***		-6.177***
		(1.855)		(2.076)
fuel cost× 2013–2014		-7.372***		-6.301***
		(1.805)		(2.035)
fuel cost× 2015–2016		-9.775***		-5.524**
		(2.065)		(2.327)
Number of observations	77,874	77,874	67,923	67,923
R-squared	0.88	0.88	0.75	0.75

* p<0.10 ** p<0.05 *** p<0.01

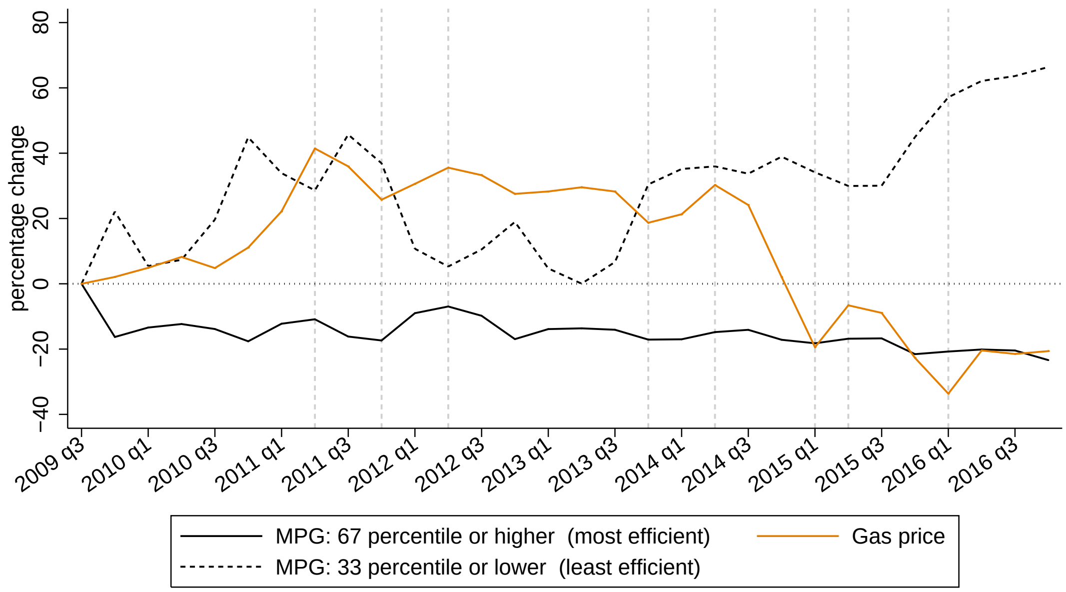
Notes: Robust standard errors clustered by vehicle trim included in parentheses. This table reports the baseline results of estimating Equation 1 by ordinary least squares. Panel A reports retail results and panel B reports fleet results. Column 1 reports baseline results from Table 3. Column 2 interacts fuel cost with four time periods.

Online Appendix

A Figures

Figure A.1: **Changes in Market Shares of Low and High Fuel Economy Vehicles with Gasoline Prices, 2010–2016**

Panel A. Retail registrations by households



Panel B. Fleet registrations

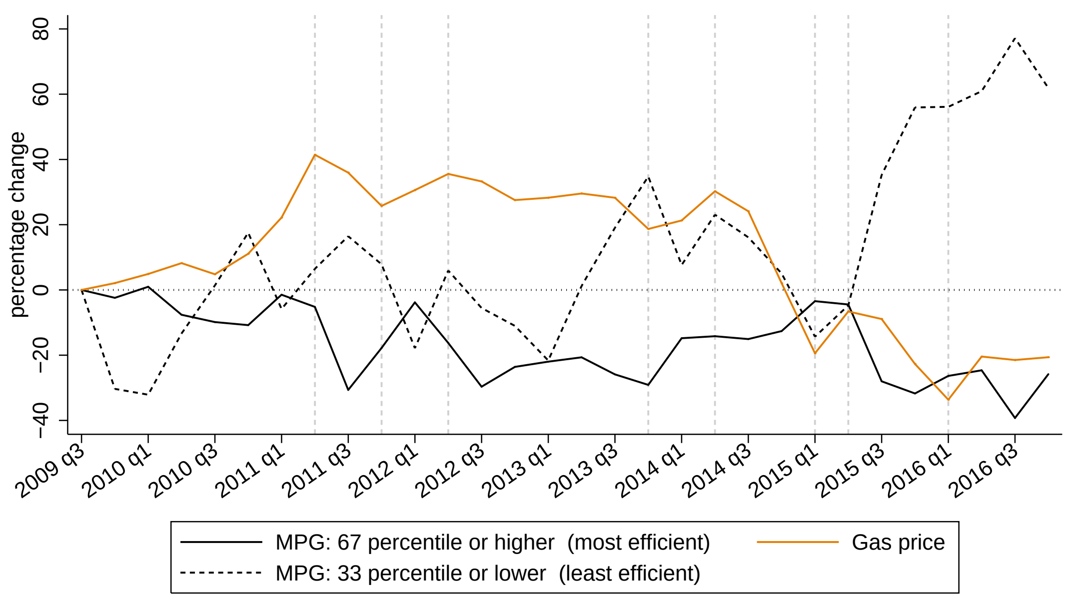


Figure A.2: **Gasoline Prices and Fleet and Retail Average Fuel Economy, 2010–2016**

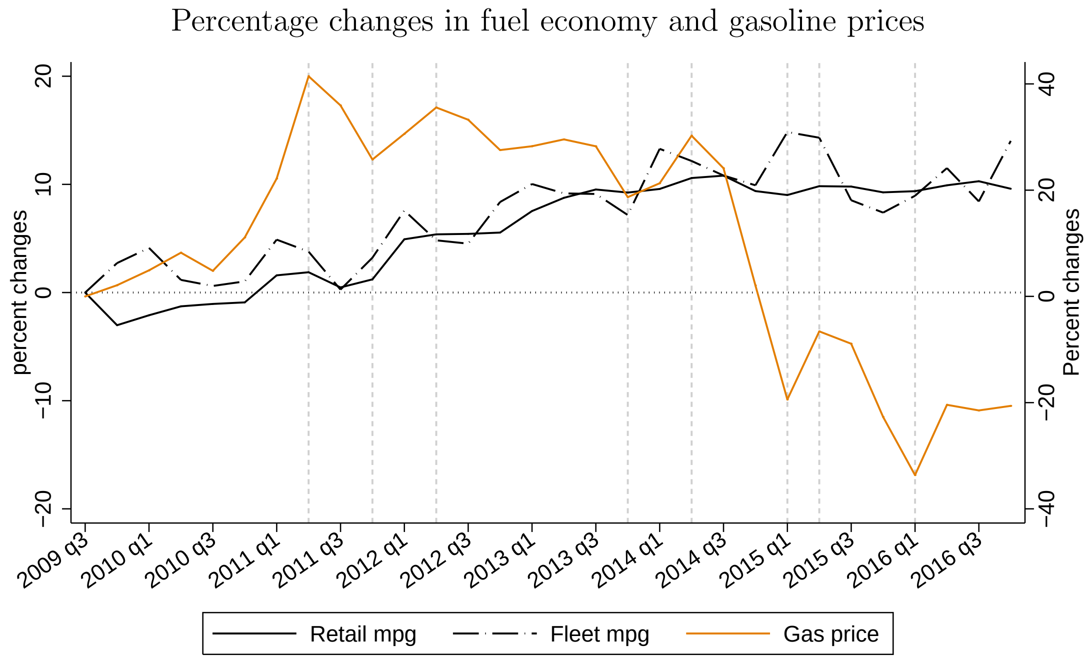
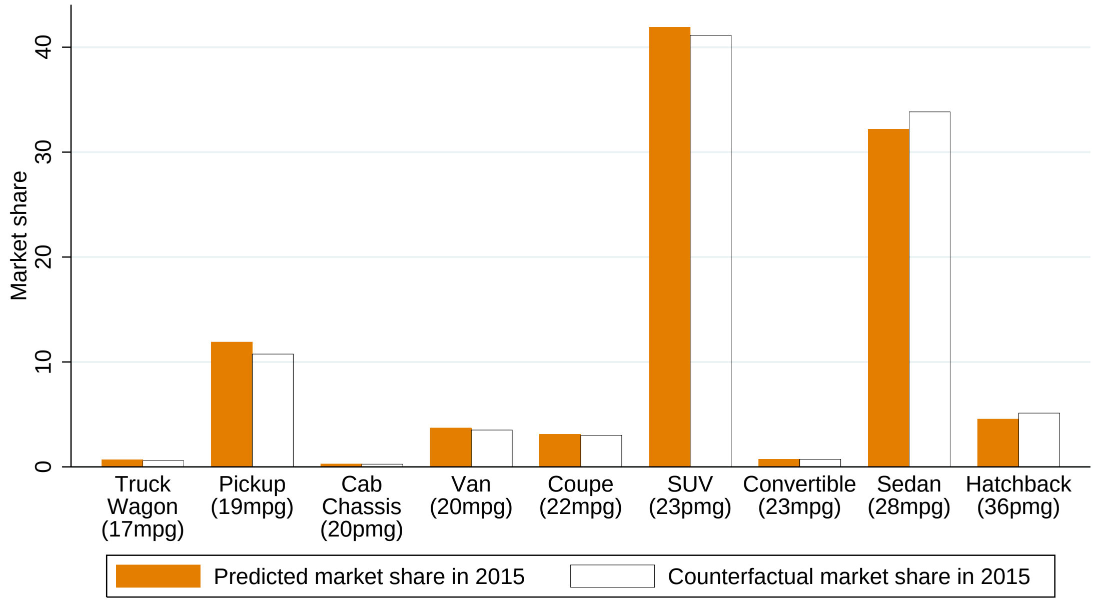
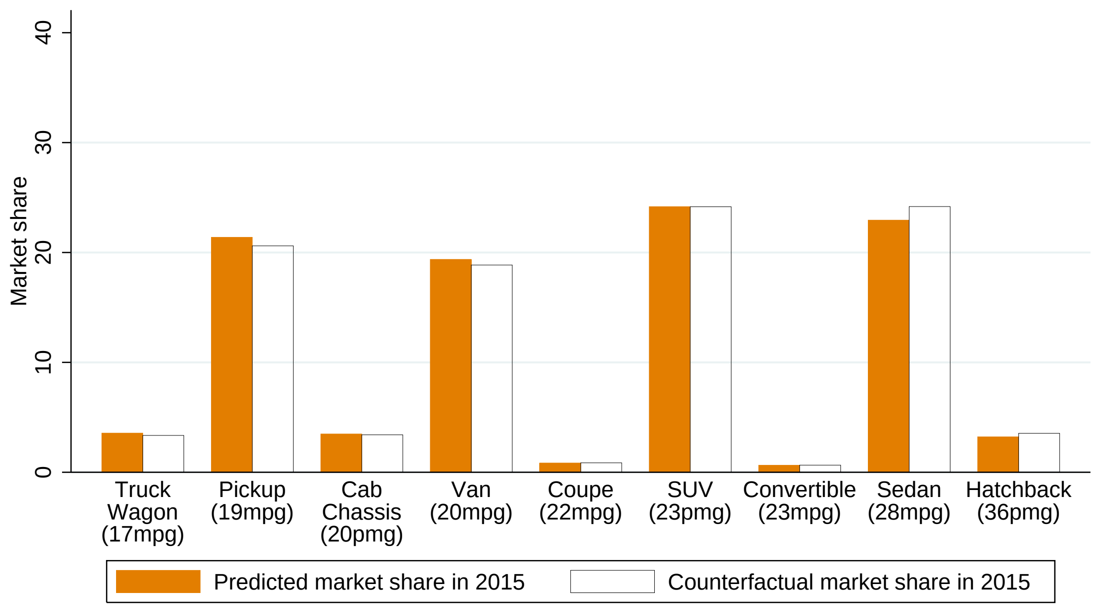


Figure A.3: **Effects of a $1 Increase in Fuel Price across Vehicle Type, 2015**

Panel A. Retail vehicles



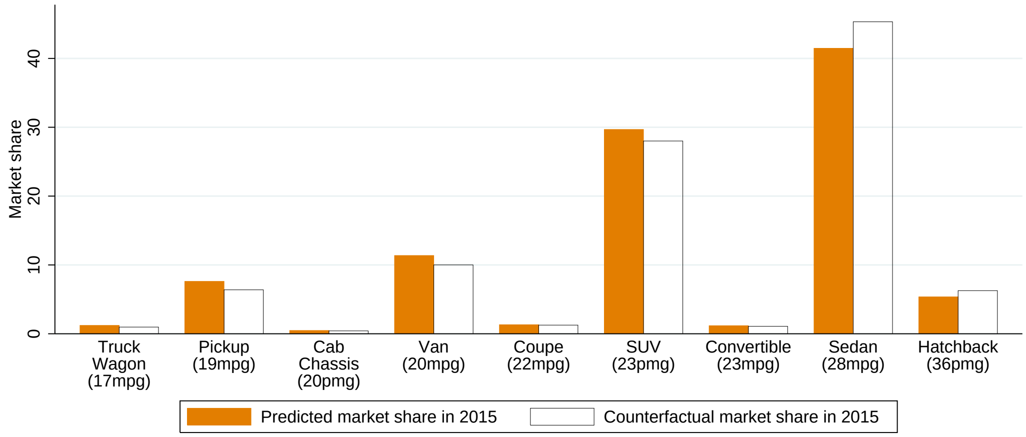
Panel B. Fleet vehicles



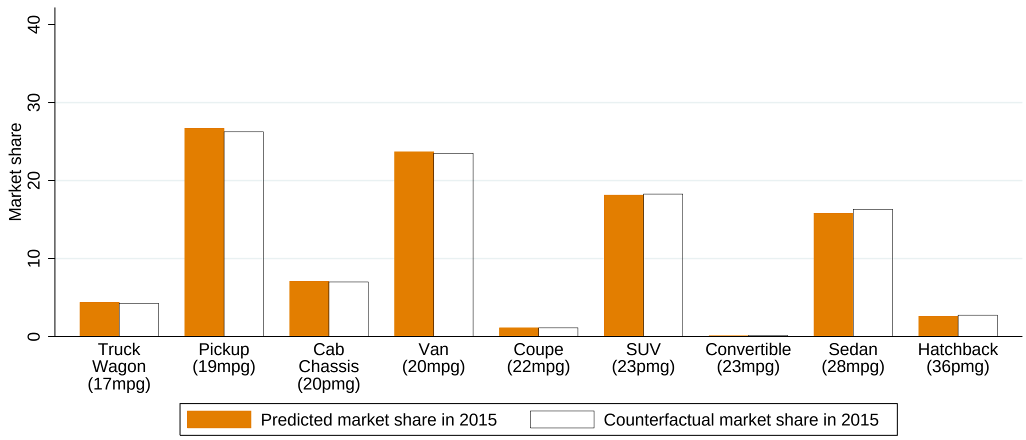
Notes: In this figure we consider a fuel price increase of $1/gallon in 2015, from $2.25/gallon to $3.25/gallon. This is similar to holding fuel price constant at 2013 level when the average fuel price was $3.29/gallon. All prices are in 2010 US dollar. For each body style in parentheses we report the national fleet average of fuel economy ratings in 2015.

Figure A.4: **Effects of a $1 Fuel Price Increase among Fleet Buyers, 2015**

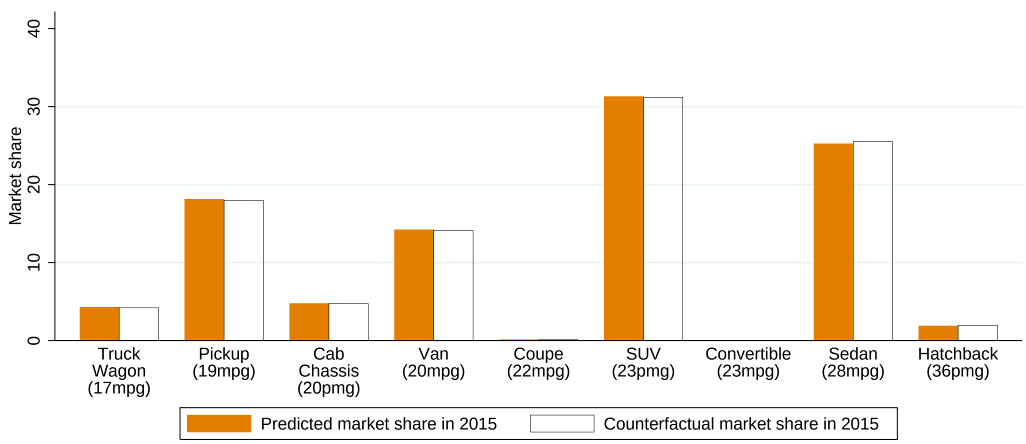
Panel A. Rental companies



Panel B. Commercial companies



Panel C. Government



Notes: In this figure we consider a fuel price increase of $1/gallon in 2015, from $2.25/gallon to $3.25/gallon. This is similar to holding fuel price constant at 2013 level when the average fuel price was $3.29/gallon. All prices are in 2010 US dollars. For each body style in parentheses we report the national fleet average of fuel economy ratings in 2015.

B Tables

Table B.1: **Effect of Fuel Cost Changes on New Vehicle Registrations by Fuel Economy Group, 2009–2016**

Dependent variable: log registrations	A. Retail		B. Fleet	
	(1)	(2)	(1)	(2)
	Baseline		Baseline	
fuel cost	-7.391***		-5.911***	
	(1.801)		(2.010)	
fuel cost× 1st mpg quartile (least efficient)		-6.126***		-7.009***
		(1.814)		(2.055)
fuel cost× 2nd mpg quartile		-8.646***		-6.867***
		(2.272)		(2.539)
fuel cost× 3rd mpg quartile		-6.011**		-8.915***
		(2.358)		(2.720)
fuel cost× 4th mpg quartile (most efficient)		-4.463		-9.684***
		(2.717)		(2.921)
Number of observations	77,874	77,874	67,923	67,923
R-squared	0.88	0.88	0.75	0.75

* p<0.10 ** p<0.05 *** p<0.01

Note: Robust standard errors clustered by vehicle trim included in parentheses. This table reports the baseline results of estimating Equation 1 by ordinary least squares. Panel A reports retail results and panel B reports fleet results. Column 1 repeats baseline results from Table 3. Column 2 interacts fuel cost fuel economy quartile group dummies.

Table B.2: **Effect of Fuel Cost Changes on Retail and Fleet New Vehicle Registrations: Alternative Standard Errors**

Panel A. Retail and Fleet, 2009 – 2016

Dependent variable: log registrations	(1)	(2)
	Retail	Fleet
fuel cost (dollars per mile)	-7.391***	-5.911**
	(2.342)	(2.342)
Number of observations	77,874	67,923
R-squared	0.88	0.75
* p<0.10 ** p<0.05 *** p<0.01		

Panel B. Retail and Fleet Subgroups, 2015 – 2016

Dependent variable: log registrations	(1)	(2)	(3)	(4)	(5)
Buyer types in samples:	retail	fleet all	fleet rental	fleet commercial	fleet government
fuel cost (dollars per mile)	-8.488***	-5.185*	-14.516***	-2.449	-1.535
	(2.447)	(2.704)	(4.359)	(2.780)	(4.545)
Number of observations	22,963	33,738	9,445	11,093	5,150
R-squared	0.89	0.59	0.84	0.86	0.85
* p<0.10 ** p<0.05 *** p<0.01					

Note: Robust standard errors clustered by vehicle model included in parentheses. This table reports the baseline results of estimating Equation 1 by ordinary least squares. The dependent variable is log of number of registrations by vehicle stub, buyer type (retail or fleet) and quarter in each calendar year. All specifications include quarter fixed effects. All specifications also include vehicle stub (including model year) by market year fixed effects. A vehicle stub is defined by a unique combination of a unique vehicle model name in IHS, series name in IHS, fuel type, body type, drive type, and liters of displacement. A market year is defined from the fourth quarter of previous year to the third quarter of current year. Column 1 reports retail results and column 2 reports the fleet results.

Table B.3: **Accounting for Potential Bias from Economic Conditions and Demand Shocks, 2009–2016**

Dependent variable: log registrations	(1) Baseline	(2) Omit 2009	(3) Demand shock	(4) Demand shock	(5) Demand shock
Panel A. Retail					
fuel cost (dollars per mile)	-7.391***	-6.601***	-6.327***	-6.854***	-7.782***
	(1.801)	(1.789)	(1.859)	(1.674)	(1.808)
truck × quarter trend			Y		
make × truck × quarter trend				Y	
luxury × quarter trend					Y
Number of observations	77,874	75,806	77,874	77,874	77,874
R-squared	0.88	0.88	0.88	0.88	0.88
Panel B. Fleet					
fuel cost (dollars per mile)	-5.911***	-5.868***	-5.773***	-5.476***	-6.352***
	(2.010)	(2.001)	(2.026)	(1.841)	(2.017)
truck × quarter trend			Y		
make × truck × quarter trend				Y	
luxury × quarter trend					Y
Number of observations	67,923	66,269	67,923	67,923	67,923
R-squared	0.75	0.75	0.75	0.75	0.75

* p<0.10 ** p<0.05 *** p<0.01

Notes: Robust standard errors clustered by vehicle trim included in parentheses. This table reports the baseline results of estimating Equation 1 by ordinary least squares. Panel A reports retail results and panel B reports fleet results. Column 1 repeats baseline results in Table 3. In column 2 we drop quarters 3 and 4 in 2009. We include truck by a quarter trend in column 3, a make by truck by quarter trend in column 4, and a luxury dummy interacted with a quarter trend in column 5. We define the luxury dummy if an observation's MSRP is higher than 95 percentile in the calendar year.

Table B.4: **Model Estimates at Alternative Levels of Aggregation, 2009–2016**

Dependent variable: log registrations	(1)	(2)	(3)	(4)	(5)
	Baseline				
A stub is defined as	trim fuel type body style drive type liter	trim fuel type body style drive type	trim fuel type body style	trim fuel type	trim
Panel A. Retail					
fuel cost (dollars per mile)	-7.391***	-7.488***	-8.036***	-7.846***	-7.663***
	(1.801)	(1.808)	(1.892)	(1.898)	(2.084)
Number of observations	77,874	69,229	54,000	47,511	43,393
R-squared	0.88	0.87	0.88	0.88	0.88
Panel B. Fleet					
fuel cost (dollars per mile)	-5.911***	-5.506***	-6.040***	-4.915**	-2.651
	(2.010)	(2.120)	(2.073)	(2.177)	(2.796)
Number of observations	67,923	61,408	49,764	45,632	41,720
R-squared	0.75	0.75	0.76	0.76	0.76

* p<0.10 ** p<0.05 *** p<0.01

Notes: Robust standard errors clustered by vehicle trim included in parentheses. This table reports the baseline results of estimating Equation 1 by ordinary least squares. The dependent variable is log of number of registrations by stub, buyer type (retail or fleet) and quarter in each calendar year. All specifications include quarter fixed effects. All specifications also include vehicle stub (including model year) by market year fixed effects. A vehicle stub is a unique is defined by a combination of a unique vehicle model name in IHS, series name in IHS, fuel type, body type, drive type, and liters of displacement (including vehicles with missing displacement). A market year is defined from the fourth quarter of previous year to the third quarter of current year. Panel A reports retail results and panel B reports fleet results. Column 1 repeats baseline results in Table 3. In columns 2, 3, 4, and 5, we define a unique vehicle stub in more aggregate levels.

Table B.5: **Lags, Forwards, and Other Potential Bias, 2009–2016**

Dependent variable: log registrations	(1)	(2)	(3)	(4)
	Baseline	Drop if displacement missing	Finite distributed lag model	Add forwards
Panel A. Retail				
fuel cost (dollars per mile)	-7.391***	-7.352***	-9.262***	-6.856***
	(1.801)	(1.825)	(2.0.98)	(1.871)
fuel cost, 1-quarter lag			1.374	
			(1.823)	
fuel cost, 1-quarter lag			3.882**	
			(1.544)	
fuel cost, 1-quarter forward				-2.146
				(2.147)
fuel cost, 1-quarter forward				6.252***
				(1.976)
Number of observations	77,874	77,543	77,874	74,118
R-squared	0.88	0.88	0.88	0.88
Panel B. Fleet				
fuel cost (dollars per mile)	-5.911***	-5.782***	-8.432***	-3.687*
	(2.010)	(2.024)	(2.105)	(2.109)
fuel cost, 1-quarter lag			4.457**	
			(1.961)	
fuel cost, 1-quarter lag			-0.835	
			(2.049)	
fuel cost, 1-quarter forward				-8.305***
				(2.408)
fuel cost, 1-quarter forward				5.013**
				(2.310)
Number of observations	67,923	67,923	67,923	55,225
R-squared	0.75	0.75	0.75	0.77
* p<0.10 ** p<0.05 *** p<0.01				

Notes: Robust standard errors clustered by vehicle trim included in parentheses. This table report the baseline results of estimating Equation 1 by ordinary least squares. Panel A reports retail results and panel B reports fleet results. Column 1 repeats baseline results in Table 3. In column 2, we drop observations if displacement is missing. In column 3 we include lagged fuel cost up to 2 quarters and in column 4 we include one-quarter lead and two-quarter lead of the fuel cost variable.