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RESOURCES FOR THE FUTURE

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 demand in the United States. Yet little is known about fleet demand for new vehicle fuel economy including how it responds to fuel price changes. In this paper, we examine economic reasons of why fleet managers might adjust vehicle purchases in response 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 increase relative to high fuel economy vehicles when gasoline prices fall. Contrary to anecdotal evidence that fleet demand is unresponsive to fuel price changes, our finding is consistent with fleet buyers taking into account capitalization of fuel costs in the second-hand market. We compare the fleet demand response to household demand during the same period and find that, on average, household and fleet buyers respond to fuel prices changes in similar ways. This result justifies 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 unresponsive.

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 empirical demand literature has provided 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 sales every year in the United States.[1] Existing models of vehicle demand that examine the effectiveness and welfare implications of policies designed to improve environmental outcomes from light-duty vehicles assume that household and fleet buyers respond in the same way to changes in the cost of vehicle ownership and use. However, fleet managers' choices about new vehicle purchases are different from those of the heads of households, but there has been little empirical analysis on this topic. 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 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.

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 (e.g., Bento et al. 2009; Jacobsen 2013). Other studies have assumed that household and fleet buyers have identical preferences for fuel cost savings and other vehicle attributes (e.g., 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 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 (e.g., Leard et al. 2017b) and studies estimating passenger vehicle demand while controlling for fuel cost savings (e.g., Reynaert 2015; Klier and Linn 2012; Whitefoot et al. 2017). There are also studies that explore counterfactual fuel consumption policies such as fuel taxes and carbon taxes that affect fuel prices (e.g., Klier and Linn 2010; Klier et al. 2017). Given that fleet vehicle demand constitutes a large share of overall new passenger vehicle demand, finding a significant deviation in fleet demand from household demand would

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

suggest past studies have overestimated or underestimated the effect of consumer willingness to pay for fuel cost savings. Similarly, rejecting such deviation would justify the assumptions of identical demand used in previous studies.

Fleet buyers may be either sensitive or insensitive to fuel cost changes for various reasons. First, government agencies can be insensitive to fuel cost savings from fuel price changes if a principal-agent problem is present. 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). Second, federal regulations and subsidy incentives may discourage government buyers from responding to energy price changes (Li et al. 2015).[2] Third, government and commercial fleets may have specific vehicle uses and requirements that limit their choices, causing government and commercial fleet buyers insensitive to fuel cost changes.

Finally, 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 for upstream manufacturers and "buy-back" options in contracts with upstream manufacturers may cause rental car companies to not respond to fuel price changes, or respond less than household vehicle buyers. From discussions with major automakers, we learned that some contracts specify that rental car companies purchase models that are not selling well to household buyers. Upstream carmakers can specify certain models they are willing to buy back, which would reduce consideration of fuel cost in 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 that profits in the rental car industry depend critically on the resale value of vehicles to 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.[3] 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.

[2] 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.

[3] 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).

This paper estimates the effect of fuel prices on the number and type of vehicles purchased by household and fleet buyers. We use a 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 (e.g., Honda Accord LX 2016, coupe, gasoline powered, front-wheel drive, 2.4-liter displacement engine) in a particular model year and market year and the type of buyer.

For the period from 2010 to 2016, we find that household buyers and fleet buyers respond to fuel costs in similar ways. We find that on average, a one percent increase in fuel cost (dollars-per-mile) reduces demand by 7 percent for household buyers and 6 percent for fleet buyers.[4] 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.

This paper contributes to the literature of fuel consumption policies in several ways. First, our estimates of the demand response to fuel price changes contribute to the small literature on how fleet buyers respond to energy prices. Li et al. (2015) find no effect of energy price on the US bus fleet.[5] 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 and other policies for new vehicles. Second, our study is the first to compare the behavior of household buyers and fleet buyers in the new car market. We find that fleet buyers have a similar response to fuel price changes as household buyers. Our study, therefore, contributes by offering justifications for

[4] Both magnitudes are similar to previous estimates (Klier and Linn 2010; Leard et al. 2017a).

[5] 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 (Rust 1987; Wollmann 2016). Moreover, it is unclear whether inferences for heavy-duty trucks demand are applicable to passenger vehicle fleet demand.

the assumption to not distinguish the two vehicle markets that is commonly made in the literature.[6]

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 alone, 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 an important market share, accounting for 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.[7] Rental company purchases account for the largest share. In the first quarter of 2015 alone, rental companies registered 0.58 million new vehicles, accounting for 86 percent of the overall 0.67 million new vehicles registered by fleet buyers. Commercial fleets make up 8 percent of the total and government buyers only 5 percent. Panel B of Figure 1 also shows that 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 2, 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 possibly would not respond

[6] Another commonly used assumption in these studies is the random walk assumption of fuel prices. Recently, Anderson et al. (2013) offer justifications for using the current gasoline price for the expected gasoline price.

[7] Detailed subfleet registrations data are available only from 2015 and 2016.

to fuel price changes when purchasing new vehicle. In Figure 2, we plot the distribution of body style for each buyer type. The distribution of body styles suggests 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.[8] 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 both 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 2 describes some of the interactions rental companies have with upstream automobile manufacturers, including, manufacturerers "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 private 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 might be constrained by what the manufacturers offer them. However, there are also reasons that many rental car companies may consider fuel cost in their decision of vehicle purchases. In Figure 2, we plot the distribution of body style

[8]For example, the Executive Order 13693 in 2015 imposes a fuel economy requirement for federal vehicle purchases. Details can be found here.

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.[9] 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 price (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.[10] For example, if gasoline prices are low or falling, rental companies will want to buy more large 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. The effect could be even stronger in the rental car market because vehicles are held for relatively much shorter time than households. Because rental companies hold vehicles for such a short time, they are likely to be particularly responsive to the vehicle resale value which depends on the expected fuel price.[11]

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] The new vehicle market was hit in 2008 by the recession but had gradually returned to the pre-recession level around Q3 2009. To avoid using the recession years, we selected the third quarter of 2009 as the first quarter of observation.[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

[9]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 here. Other companies operate similarly.

[10]A discussion of the importance of resale value to rental fleets can be found here.

[11]Anderson et al. (2013) show that households take the current fuel price as the best prediction for the expected fuel price. Rental companies are therefore likely to be sensitive to the resale value, which depends on the current fuel price.

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

[13]In Section 4.3, we test the robustness of our results by omitting time periods close to the end of the great recession.

"fleet" registrations type refers to the number of vehicles registered by private companies and government agencies for their commercial or governmental activities.

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 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.[15]

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

[15] 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 at

2.3 Summary Statistics and Suggestive Evidence

From the third quarter of 2009 to mid-2011, the US economy experienced a rapid rise in fuel prices, as shown in Figure 4. Gasoline prices, for example, rose from $2.50 to more than $3.50 per gallon. This increase was followed by stable gasoline prices from mid-2011 to 2013, a rapid drop in gasoline price in 2014, and a period of fluctuation from 2015 to 2016. Table 1 reports summary statistics for for each two years from 2009 to 2016. Panel A reports summary statistics for individual households, and panel B reports details for all fleet buyers. The average number of registrations 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.

To preview the identifying variation we exploit in this paper, we plot in Figure 5 the temporal changes in 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 gasoline prices sharply dropped from Q2 2014 to Q1 2015, passenger cars experienced a moderate decrease in market share. In contrast, light-duty trucks experienced a roughly 10 percent increase 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: as fuel price increases (decreases), low fuel economy vehicles would gain (lose) in relative market share, and high fuel economy vehicles would lose (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 5. 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 sales to fleets are highest in the first quarter of every year when retail sales are sluggish, and lowest in the third and fourth quarters when 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 fell from Q2 2014 to Q1 2015, initially truck shares declined and

gasoline mode, MPK at electricity mode, gasoline price, electricity price, and predicted fraction of electricity usage from EPA.

car shares rose, the opposite of what we expect. However, with the subsequent decline in gasoline prices after Q2 2015, truck shares increased strongly, rising from close to their 2010 level to 50 percent higher by Q3 2016.

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 sales 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 the sales response to this and continued 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. Sales shares of cars and trucks remained relatively constant over time, with a slight trend downward for cars and up for trucks.[16] Later in Section 4.4, 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 response of new vehicle demand to fuel price fluctuations for a given model year and a market year. 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:

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

where fc_{it} 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. Fuel cost fc_{it} is the ratio of fuel price fp_{it} in quarter t to the fuel economy rating $mpg_{i,my}$ of vehicle i in model year my (we suppress

[16]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. We plot percentage changes of gasoline prices, average fuel economy for individual household registrations, and average fuel economy for fleet registrations. Because fuel price changes may shift the quantity of demand across different vehicles as depicted in the above figures, and that quantity of equilibrium demand may affect product mix and weighted average fuel economy, we might expect to see average fuel economy respond accordingly.

the subscript for model year throughout this paper).[17] Vehicle i is a unique vehicle stub. It represents a unique combination of 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 $\boldsymbol{X}_{it}$ to control for unobserved characteristics possibly correlated with fuel costs. Some of these fixed effects are likely to be different for retail vehicles and fleet vehicles. First, vector $\boldsymbol{X}_{irt}$ includes the fixed effects of 30 quarters in our sample to capture all unobserved aggregated supply and demand shocks.[18] These quarterly fixed effects are likely to be different for retail and fleet vehicles.[19] Figure 1 shows the different cyclical patterns for the two vehicle types. Retail vehicle sales from individual households tend to peak early in the market year, and fleet vehicle sales peak at the beginning of the calendar year.

Second, vector $\boldsymbol{X}_{irt}$ includes a fixed effect for each vehicle stub i interacted by model year my and interacted by market year mt. 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. Controlling vehicle stubs and model years allows us to capture unobserved vehicle characteristics that are constant within a model year, hold them constant, 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 model year my with market years mt to compare vehicles offered within a market year.

Controlling for all observed and unobserved influences allows us to identify the parameters of interest β_r. Consider a particular vehicle in a model year purchased in a particular market year, for example, Honda Accord Model Year 2015 EX gasoline powered front-wheel-drive

[17]Fuel price fp_{it} is vehicle specific. Depending on the automotive engine, the quarterly fuel price can be gasoline price, diesel price, electricity price, or a combination of gasoline price and electricity price. For electric vehicles (EVs), the fuel cost is the ratio of electricity price and energy consumption 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.

[18]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).

[19]Given that Equation (1) includes quarter by buyer type fixed effects, estimates of β_r in Equation (1) are identical to a model where the dependent variable is the log of buyer type sales share, which has been used in previous analyses, e.g., Leard et al. (2017a).

sedan with a 2.4-liter engine purchased in the market year 2016. Our parameter β_r is identified from computing changes in fuel prices within that market year (e.g., variation in fuel prices between Q4 2015 to Q3 2016) for that vehicle and comparing this with other vehicles. 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 drop in the gasoline price reduces cost per mile of the SUV by 5 cents and the hybrid by 2.5 cents, making the SUV relatively cheaper to drive. This change in fuel price increases the demand for the SUV relative to the hybrid (although both could increase in response to falling gasoline prices). The demand shift results in a movement along the new vehicle supply curves, causing manufacturers to adjust new vehicle prices in the short term, for example, for next market year holding model year constant. 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.[20] Equation (1) incorporates both of these supply-side responses since we do not control for temporal changes in new vehicle prices.

The interactions of stub by 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 registration. 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.

[20] Leard et al. (2017a) argue that this may dampen the effect of fuel price changes on market share. By the same argument, this effect may dampen the effect of fuel prices on the quantity of demand focused in this paper.

We expect the coefficients of interest, β_r, to be negative. A decrease in the fuel price lowers the cost per mile of driving for all vehicles. The fuel price decrease, however, lowers the cost per mile more for vehicles with low fuel economy than for vehicles with high fuel economy. Therefore, the fuel cost of the vehicle with low fuel economy falls relative to the fuel cost of the vehicle with high fuel economy. The decrease in relative fuel costs causes willingness to pay for vehicles with high fuel economy to fall and the willingness to pay for vehicles with low fuel economy to rise.

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 triple interacted term of vehicle stub by 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 our fleet regressions in column 2 because individual households purchased more distinct vehicle stubs than did fleet buyers during our sample period.

We begin with the retail market. 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 $1 increase in fuel price 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]

[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 a more conservative standard error using robust standard error clustered at vehicle model level. Our results are robust to alternative standard errors.

[22] Leard et al. (2017a) estimate log market share on monthly dollar-per-mile fuel costs from 2003 to 2015 and find the estimate is around -7.72. Klier and Linn (2010) estimate log sales on monthly dollar-per-mile costs from 1978 to 2007 and find the estimate is around -10.55.

The key focus question this paper aims to address is whether fleet buyers respond to fuel price changes. This will influence the effectiveness of fuel consumption policies. 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 $1 increase in fuel price 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 2, we find on average fleet buyers do respond to fuel price changes. In next section 4.2, we explore further how different subgroups of fleet buyers respond to fuel price change.

Our secondary interest of this paper is to compare how the retail market and the fleet market respond to fuel price changes. The answer to this question is important for fuel economy and welfare implications of existing studies on vehicle market and fuel consumption policies. 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 between fuel cost 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 triple interaction term of vehicle stub, 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 cost 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 magnitudes. Until more data is available, it is a reasonable assumption that the fleet and retail agents respond in similar ways to fuel price changes.

Table 6 further investigates whether the pattern of consumer response to fuel price varies over time. As shown in Figure 4, the fuel prices have had several periods of low variation and several periods of high variation. To allow the effect of fuel price 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 cost (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]

[23] In addition, we find in Appendix Table B.1 that buyer's response are similar across fuel economy groups.

The estimates in Tables 3 and 6 and the test results in Table 5, 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 are the same in both retail and fleet markets. Our results imply that this assumption is statistically valid, at least for the period considered here. It is a reasonable simplifying assumption not to separate fleet buyers from household buyers in modeling vehicle demand, given the current make up of the fleet vehicle mix.

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 the retail market during this limited time period, as shown 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

The most important question we aim to answer in this subsection is whether specific groups respond to fuel price changes at all. 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 very sensitive to fuel price changes. Using the same example as in Section 4.1 to interpret Table 4 , column 3 suggests that a hypothetical $1 increase in fuel price will increase the retail market share of Honda Accords by 18.9 percent relative to Ford F-150s, and will increase the rental company market share of Honda Accords by 32.3 percent relative to Ford F-150s.

We show results for commercial companies and government units in Table 4 columns 4 and 5. The results suggest that commercial companies are less sensitive to fuel price changes than household buyers, 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 what we expect, based on what we know about these two groups of buyers as discussed in Table 2.. 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 main player in the fleet vehicle market, car rental companies which represent about 80 percent of registrations, do respond to fuel price changes. This implies that the influences causing rental car companies to be insensitive to fuel price changes such as "dumping " by the automobile companies as described in Table 2, are dominated by other incentives that cause them to respond to fuel cost changes such as "selling on the used car market". (See Table 2 for a list of incentives). These results also imply that the reasons we hypothesize for commercial companies and government buyers are present in the data They do barely respond to fuel price changes for reasons we discussed in Table 2.

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 triple interaction of vehicle stub, 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 cost 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. This result rejects the hypothesis that rental companies behave differently from household buyers in the retail market at the 10 percent level.

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 availability of more data in the future will mean we should be able to explore how these different fleet groups behave in the future. 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 with the advent of ride sharing opportunities. Ride sharing miles and their response to fuel price changes will be important to explore in future work.

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

4.3 Robustness Checks

We have previously documented the effect of fuel price changes on vehicle registrations for households purchasing at a retail market and buyers purchasing a fleet of vehicles. We have reported that household buyers and fleet buyers as a whole respond to fuel price variation in indistinguishable ways. In this section, we demonstrate that our conclusion is robust to addressing potential sources of bias and alternative assumptions.

First, we consider the possibility of unobservable demand and supply shocks due to the 2008 recession. The recession hit the new passenger vehicle market in 2008. Overall vehicle registrations were low, and did not return to the pre-recession level until Q3 of 2009. We choose Q3 2009 as the first quarter of our time span. Although the new vehicle market appears to be back to normal in Q3 2009, it is possible there remain some unobserved macroeconomic shocks. To account for the possibility of aggregate shocks, we consider a more conservative time span and omit 2009 Q3 and Q4 from our regression. Table 7 column 2 reports the estimation results. We repeat the baseline estimates in column 1 for convenience. Panel A documents the result for household buyers in the retail market, and panel B documents the result for fleet buyers. We find that omitting 2009 from our sample does not change the results – the retail coefficients and fleet coefficients are not distinguishably different. Similar to Table 5, we perform this test using a sample combining both buyer types (not reported). We reject the hypothesis that coefficients are different for these two buyers.[25]

We further 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 capture such potential shocks, we further control for a truck dummy interacted with a linear quarter trend in Table 7 column 3.[26] We find results comparable to our baseline, and no significant differences between retail and fleet coefficients.

Also, the shock in the above example can affect particular Volkswagen and Audi vehicles more than vehicles produced by other manufacturers in quarters following Q3 2015. To

[25] We perform the same test for all results in Table 7 and Table 8.

[26] In addition, we define vehicle class using body style variables (sedan, convertible, coupe, hatchback, station wagon, SUV, van, cab and chassis, pickups, and truck). We further control for class interacted with a linear quarter trend. Our result is robust to including this additional control variable (not reported).

examine this type of shock, we further control for make by truck fixed effects interacted with a linear quarter trend in Table 7 column 4. Our results are robust to these additional controls.[27]

Lastly, it is possible that the macroeconomic shock from the recession is more persistent for some vehicle models than for others. For example, an economic downturn can affect demand for luxury vehicle models disproportionately. The effect from a recession may dissipate over time, but it may dissipate faster (or slower) for luxury vehicles than for other vehicles. We interact a luxury vehicle dummy with a linear quarter trend in column 5. This specification also relaxes the assumption in our baseline that the fuel cost (dollars per mile) is exogenous to time-varying factors. Because high-income households are more likely to purchase luxury vehicles, and companies that target particular types of clients are more likely to buy luxury vehicles, the specification in column 5 allows us to capture unobserved time-varying tastes that are specific to consumer attributes. Controlling for these possibilities does not affect our main results. In conclusion, columns 3, 4, and 5 suggest that our main results are robust to allowing macroeconomic conditions to affect registrations of different vehicles disproportionately, and to allowing the macroeconomic shock to affect different vehicles at different rates over time.

Finally, in Table 8 we consider the possibility that the effect of fuel price changes on vehicle demand is not simply contemporaneous, as in our baseline. First, fuel price shocks can have persistent effects, meaning that past fuel price changes can affect current vehicle registrations. Second, using contemporaneous fuel price implicitly assumes that fuel price follows a random walk and consumers use the current fuel price as the best prediction for future prices, following empirical findings by Anderson et al. (2013). Instead, vehicle buyers may form expectations for future prices using information from previous periods. For these reasons, we include two-quarter lagged terms of fuel cost (dollar-per-mile) in Table 8 column 3. We find that the lagged fuel costs are not precisely estimated for household buyers and only the first quarter lag is precisely estimated for fleet buyers. Our main result from our baseline still holds after the including additional lagged terms.

4.4 Implications for Fuel Consumption Policies and Their Effect on Vehicle Mix

We have demonstrated in Section 4.1 that fleet buyers and retail buyers are not distinguishably different in how they respond to fuel price changes. This result implies

[27]We further control for make by class fixed effects interacted with a linear quarter trend. Our result is robust to including this additional control variable (not reported).

that a hypothetical fuel tax (or 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 fuel tax (or other fuel consumption policies) may have a similar average effect on different buyers, it is not clear whether the effects on the distribution types would be comparable as well.

We begin by investigating the average effect and the distributional effect of a fuel tax or an equivalent carbon tax. We consider a hypothetical fuel price increase of $1 in 2015, from $2.25 per gallon to $3.25 per gallon (all figures are in 2010 USD). To put this hypothetical scenario in perspective, a fuel price at $3.25 per gallon is similar to the average fuel price in 2013, which was $3.29 per gallon. This exercise is equivalent to considering a shock that bumps the current fuel price to its level in 2013.

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. The first column of Table 3 reports the counterfactual result for the retail market, and the second column reports the counterfactual result for the fleet market. Our analysis suggests that a $1 increase in the fuel price would cause the average fuel economy in 2015 to increase by 0.26 miles per gallon for household buyers in the retail market, and 0.24 miles per gallon for the fleet buyers. The similarity in magnitude suggests that a fuel tax would have a similar effect on the two markets in the short run. We further break down the effect for the four buyer types in panel B, using coefficients estimated from 2015 to 2016 in Table 4. We find most of the short-run effects of fuel price changes on average fuel economy ratings are similar.

Next, using coefficients estimated from the baseline and the counterfactual registrations produced in Table 3 panel A, we plot the market share distribution by body style in Figure A.3. Panel A plots the distribution for retail vehicles, and panel B plots the fleet vehicles. The colored bars show the predicted market share using 2015 fuel prices. The clear bars plot the counterfactual market share if fuel price had been $1/gallon higher in 2015. An equivalent interpretation for the clear bar is that the clear bars represent the counterfactual market share if fuel price had been held at 2013 level. Panel A shows that this hypothetical increase in fuel price would shift market share from pickup trucks, SUVs, and vans to the more fuel-efficient sedan and hatchbacks. The degree of such a change appears similar across both markets.

We further investigate the distributional effect for the three categories of fleet buyers in Figure A.4, using the counterfactuals produced in Table 3 panel B. In Figure A.4, panel A plots the market share distribution for rental vehicles, panel B plots commercial company vehicles, and panel C plots government vehicles. Again, the colored bars show the predicted market share using 2015 fuel prices, and the clear bars plot the counterfactual market share if fuel price had been $1/gallon higher in 2015. Figure A.4 shows that rental companies drive the most change in demand, with a slight change in demand for commercial companies, and barely any change for government units.

In conclusion, we find fuel consumption policies that affect fuel cost in the short run have similar if not identical effects on retail and fleet markets. This conclusion holds true for both the average effect as well as the distributional effects on vehicle mix.

5 Conclusion

Previous studies have documented a strong relation of fuel price changes to the quantity of new vehicle demand in the retail market. However, a large share of new vehicles are purchased by private companies and government units, i.e., "fleet" buyers. How do fleet buyers respond to fuel price changes? And how do their response compare to household buyers? Our analysis finds that on average, fleet buyers do respond to fuel price changes and they behave similarly to household buyers in the retail market.

Using a unique dataset of new vehicle registrations by buyer type from 2009 to 2016, this paper estimates the effect of fuel price changes on new passenger vehicle registrations for fleet buyers. We find a strong relation between fuel price changes and new vehicle registrations for fleet buyers. This suggests potential fuel consumption policies that target fuel prices could be effective for the fleet vehicle market.

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 based on data available. Our results suggest that a fuel tax would affect household demand and fleet demand in similar ways. Analyses calibrating demand responses using household level data are likely to be an accurate representation of the entire light-duty new vehicle demand. This reduces the need to estimate new vehicle demand curves separately for household and fleet buyers.

The results of our analysis for the components of fleet demand – rental, commercial and government – do not conclusively show differences in response to fuel price changes between these subgroups and aggregate fleet and retail buyers. But our data for these groups were limited to two years. More analysis of differences among these groups and the way ride sharing and autonomous vehicles will affect vehicle choice and miles driven in response to fuel price changes is needed as data becomes available.

There are several caveats to our analysis. First, identification in our analysis is based on quarterly variation in fuel prices. Therefore, our results should be treated as short-run demand responses. Whether household and fleet buyers respond differently to long periods of low fuel prices is out of the scope of our analysis and is left for future research. Second, we estimate the effect of fuel price changes on equilibrium market shares. 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 to fuel price changes. 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.

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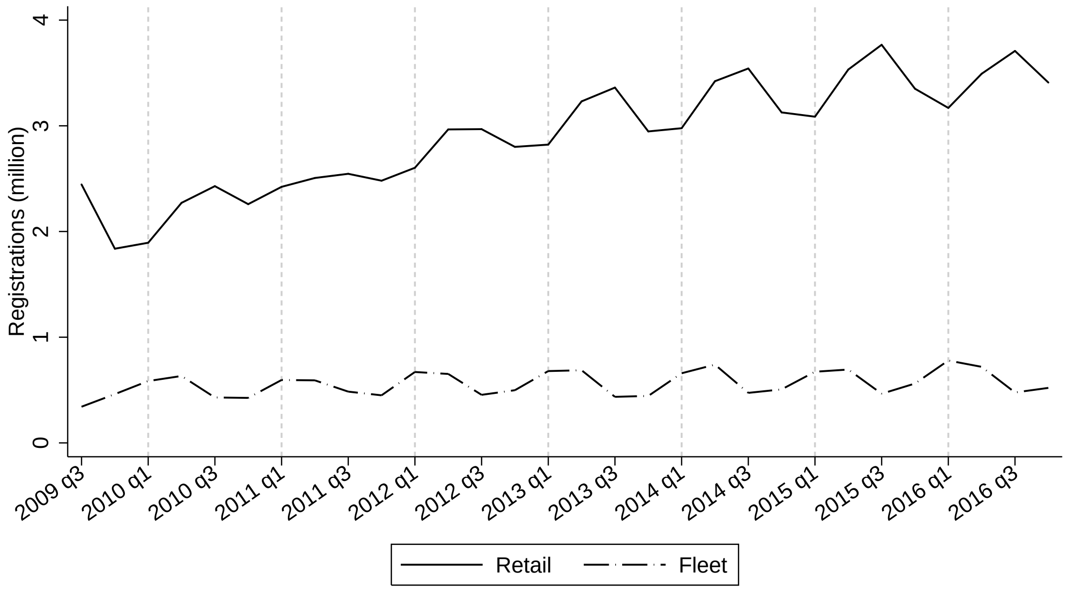
Figures

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

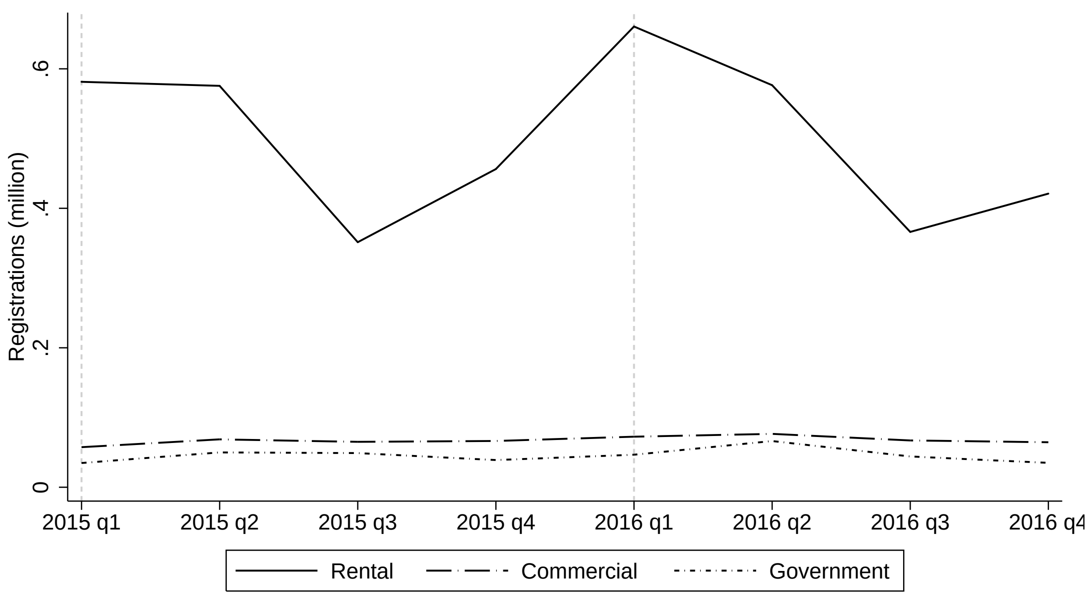


Figure 2: **Body Style Distribution by Buyer Type, 2015–2016**

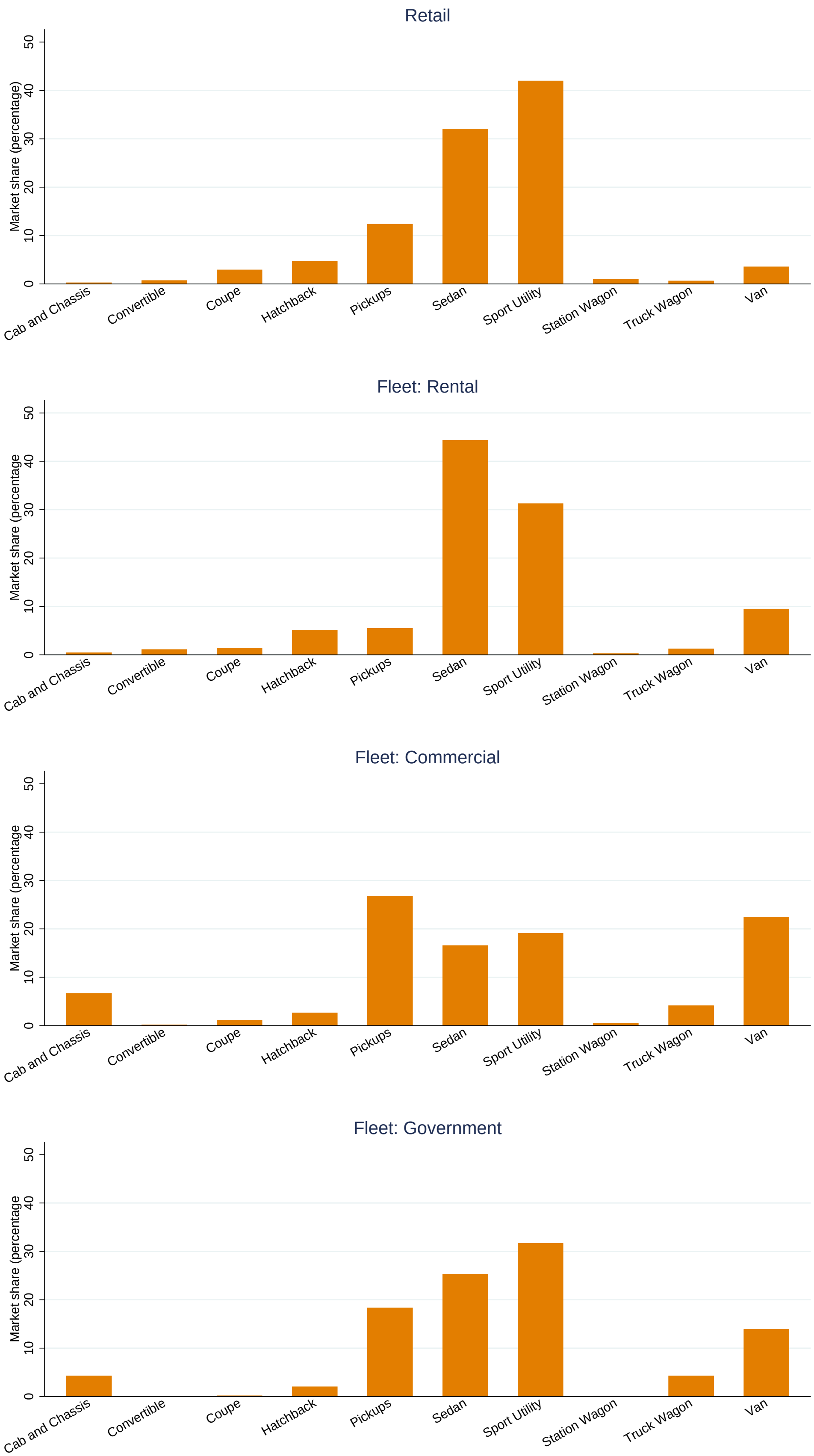


Figure 3: **Domestic and Foreign Vehicles by Buyer Type, 2015–2016**

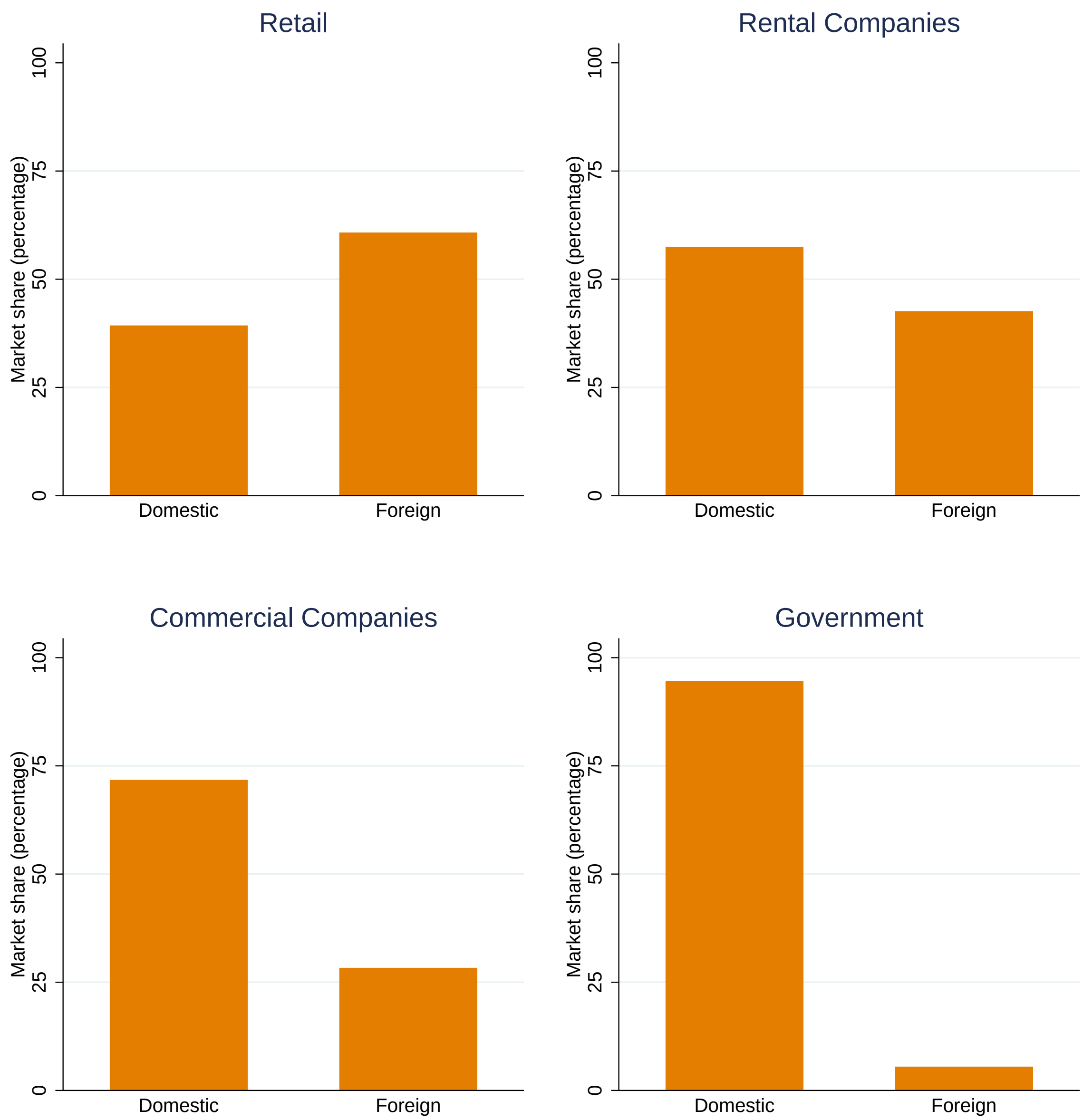
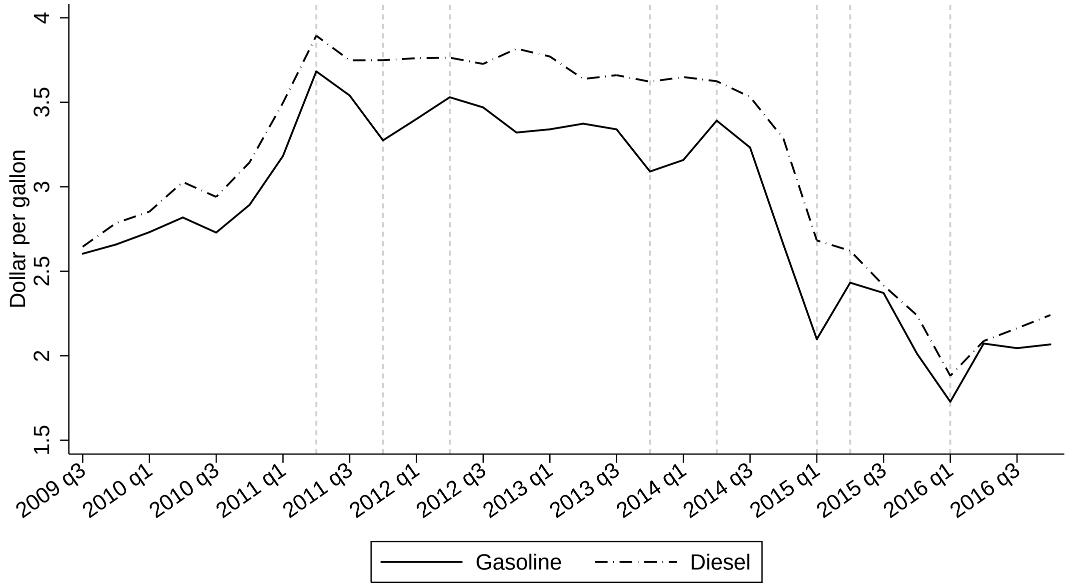


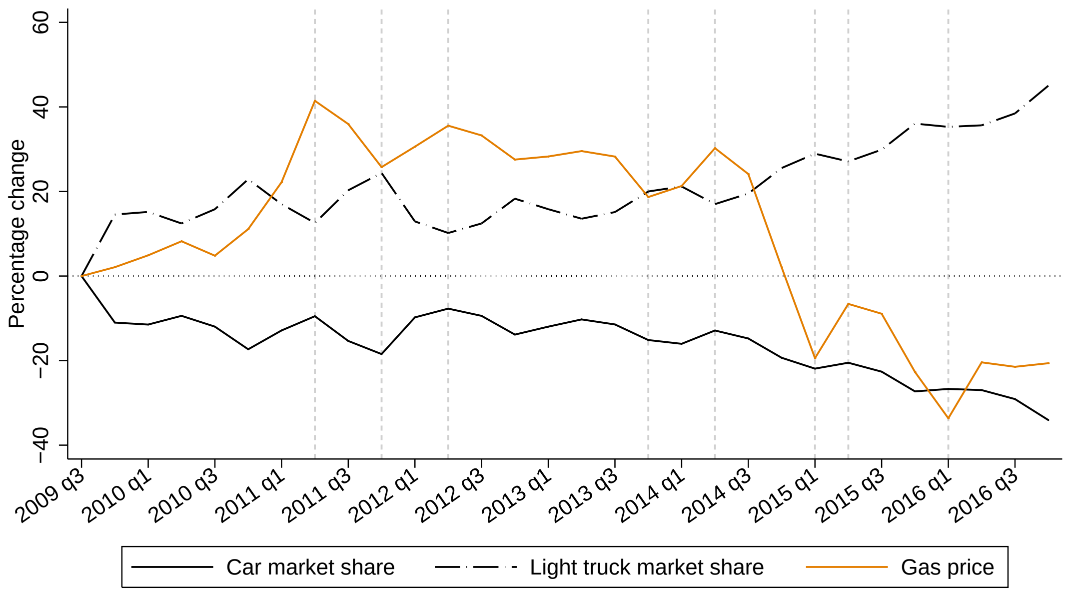
Figure 4: **Quarterly US Fuel Prices, 2010–2016**



Note: Fuel prices are in 2010 USD.

Figure 5: **Changes in Market Share of Cars versus Light Trucks and Gasoline Prices, 2010–2016**

Panel A. Retail registrations by households



Panel B. Fleet registrations

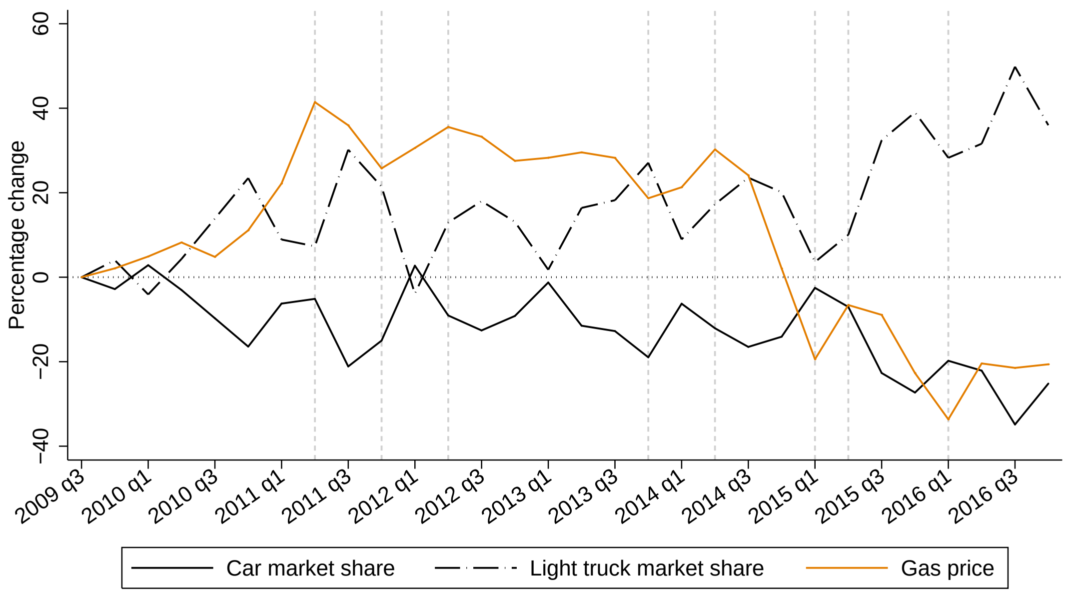
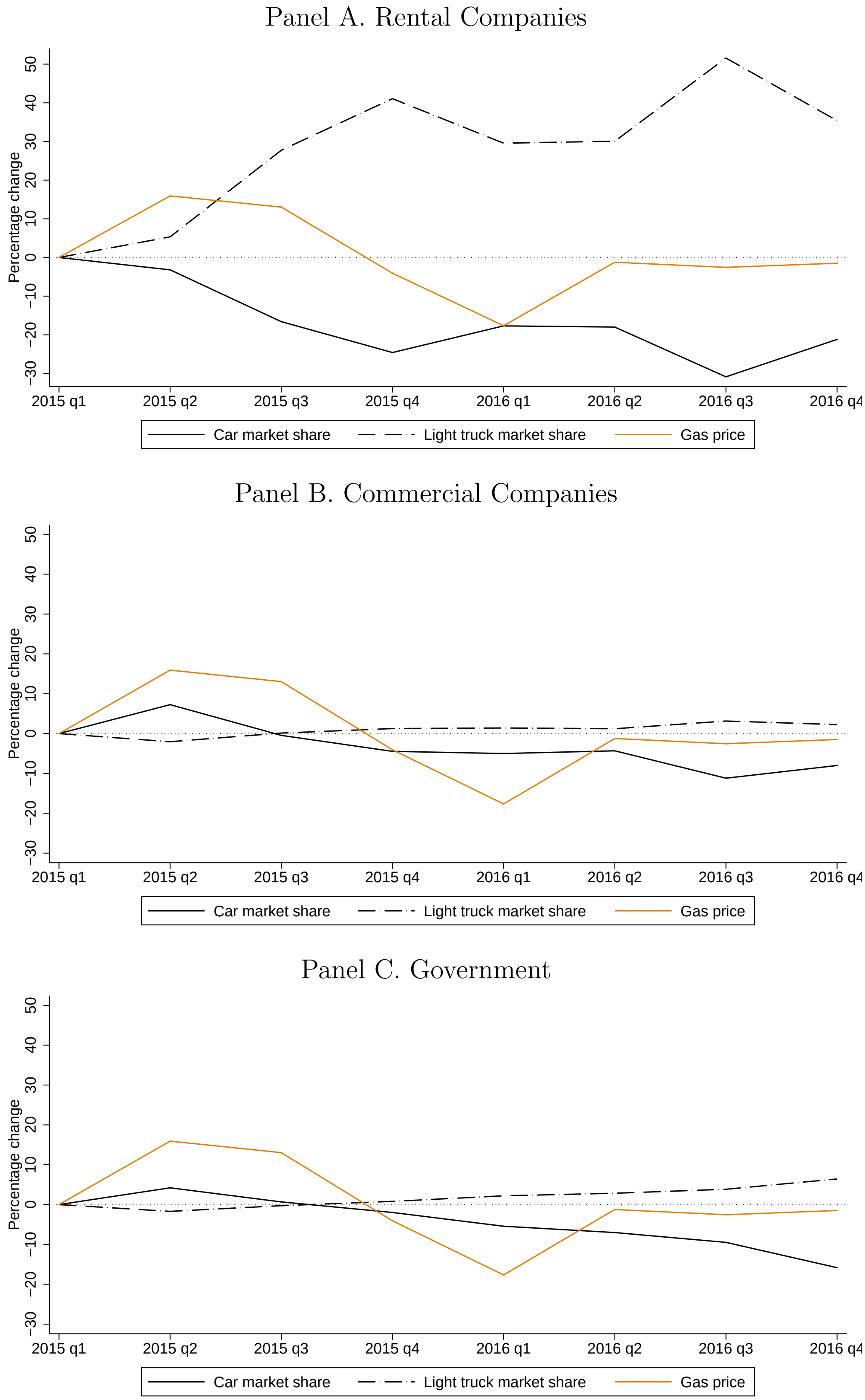


Figure 6: **Changes in Market Share of Cars versus Light Trucks and Gasoline Prices by Fleet Subgroups, 2015–2016**



Tables

Table 1: **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)	22.8	23.9	25.4	25.4
	(5.7)	(6.1)	(7.9)	(7.9)
Fuel cost (dollar per mile)	0.13	0.15	0.13	0.09
	(0.03)	(0.03)	(0.03)	(0.02)
Horsepower	216	222	225	234
	(69)	(76)	(83)	(85)
Weight (lbs)	3,739	3,743	3,780	3,846
	(807)	(798)	(798)	(773)
Truck	0.49	0.50	0.51	0.58
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	24.2	24.4
	(4.9)	(5.2)	(6.1)	(6.1)
Fuel cost (dollar 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)	(85)	(89)
Weight (lbs)	3,781	3,858	3,904	3,890
	(871)	(872)	(910)	(863)
Truck	0.44	0.46	0.48	0.50
Number models				463
Number of trims				1,645
Number of stubs				3,929

Table 2: **Reasons Why Fleet Demand May Be More of Less Sensitive to Fuel Cost Changes than Household Demand**

Reason	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.
Subsidy incentives	government	Federal government 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 vehicles government buyers can 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 upstream manufacturers for some vehicles, and may therefore be less responsive to fuel price changes.
Selling on the used vehicle market	rental car	Fleet companies sell vehicles after 12–18 months of use, and used vehicle sales are a key source of revenue.

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

Dependent variable: log registrations	(1) Retail	(2) Fleet
fuel cost (dollar-per-mile)	-7.391***	-5.911***
	(1.801)	(2.010)
Number of observations	77,874	67,923
R-square	0.88	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. 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 by 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. (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 (dollar-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-square	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 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 by 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 using 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 (dollar-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-square	0.85	0.90
* p<0.10 ** p<0.05 *** p<0.01		

Note: 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 by 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 further quarter fixed effects interacted 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). We lose some observations comparing with Table 4.

Table 6: **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 (dollar-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-square	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 reports baseline results from Table 3. Column 2 interacts fuel cost with four time periods.

Table 7: **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	-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-square	0.88	0.88	0.88	0.88	0.88
Panel B. Fleet					
fuel cost	-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-square	0.75	0.75	0.75	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 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 8: **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	-7.391***	-7.352***	-9.262***	-6.856***
	(1.801)	(1.825)	(2.0.98)	(1.871)
fuel cost, 1-quarter lag/forward			1.374	-2.146
			(1.823)	(2.147)
fuel cost, 1-quarter lag/forward			3.882**	6.252***
			(1.544)	(1.976)
Number of observations	77,874	77,543	77,874	74,118
R-square	0.88	0.88	0.88	0.88
Panel B. Fleet				
fuel cost	-5.911***	-5.782***	-8.432***	-3.687*
	(2.010)	(2.024)	(2.105)	(2.109)
fuel cost, 1-quarter lag/forward			4.457**	-8.305***
			(1.961)	(2.408)
fuel cost, 1-quarter lag/forward			-0.835	5.013**
			(2.049)	(2.310)
Number of observations	67,923	67,923	67,923	55,225
R-square	0.75	0.75	0.75	0.77
* p<0.10 ** p<0.05 *** p<0.01				

Note: 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.

Table 9: **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	-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-square	0.88	0.87	0.88	0.88	0.88
Panel B. Fleet					
fuel cost	-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-square	0.75	0.75	0.76	0.76	0.76

* 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. 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 by 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 10: **Simulate Effect of a $1 Fuel Price Increase on Average Fuel Economy by Buyer Type, 2015**

	(1)	(2)	(3)	(4)	(5)
Buyer type:	Retail	Fleet	Rental	Commercial	Government
Panel A. Coefficient from Baseline in Table 4					
Average fuel economy (miles-per-gallon) in 2015					
1. Predicted average	23.72	21.44			
2. Counterfactual average	23.99	21.67			
3. Changes	0.26	0.24			
Coefficient for fuel cost	-7.39	-5.91			
Number of observations	12,786	16,754			
Panel B. Coefficient from Table 4					
Average fuel economy (miles-per-gallon) in 2015					
1. Predicted average	23.77	21.38	23.83	20.69	20.36
2. Counterfactual average	24.10	21.57	24.45	20.84	20.36
3. Changes	0.32	0.20	0.62	0.25	0.00
Coefficient for fuel cost	-8.49	-5.19	-14.52	-2.449	-1.535
Number of observations	12,786	16,754	5,076	6,022	2,784

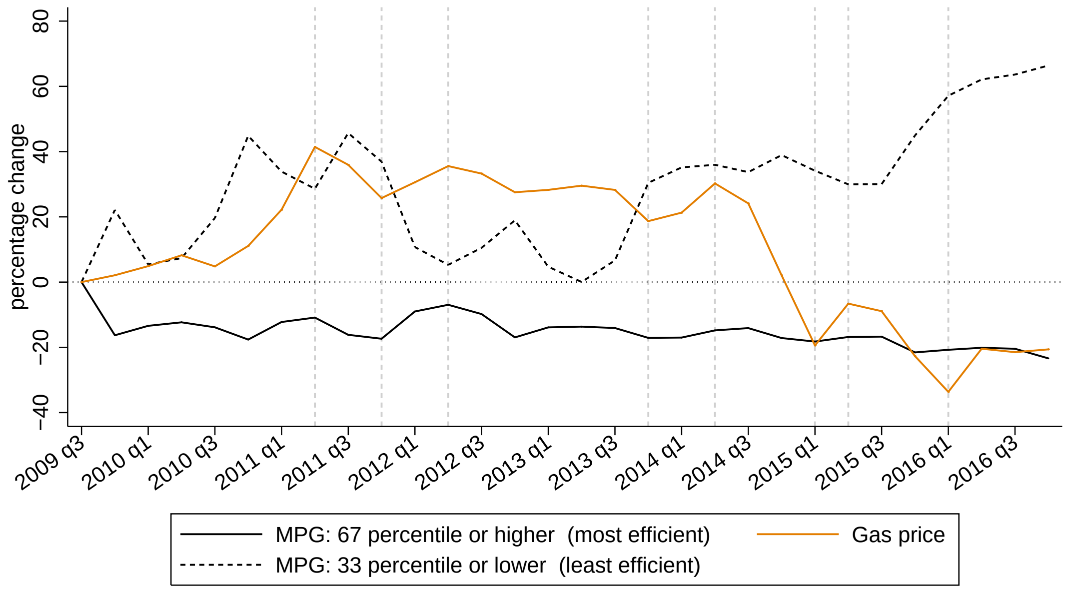
Note: Average fuel economy is harmonic fuel economy weighted by quantity. In row B.1, fuel economy is weighted using predicted number of registrations. In row B.2, fuel economy is weighted using adjusted counterfactual number of registrations. We adjust the counterfactual number of registrations using the total predicted number of registrations in 2015. We report the changes from predicted average fuel economy to counterfactual fuel economy in row B.3.

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

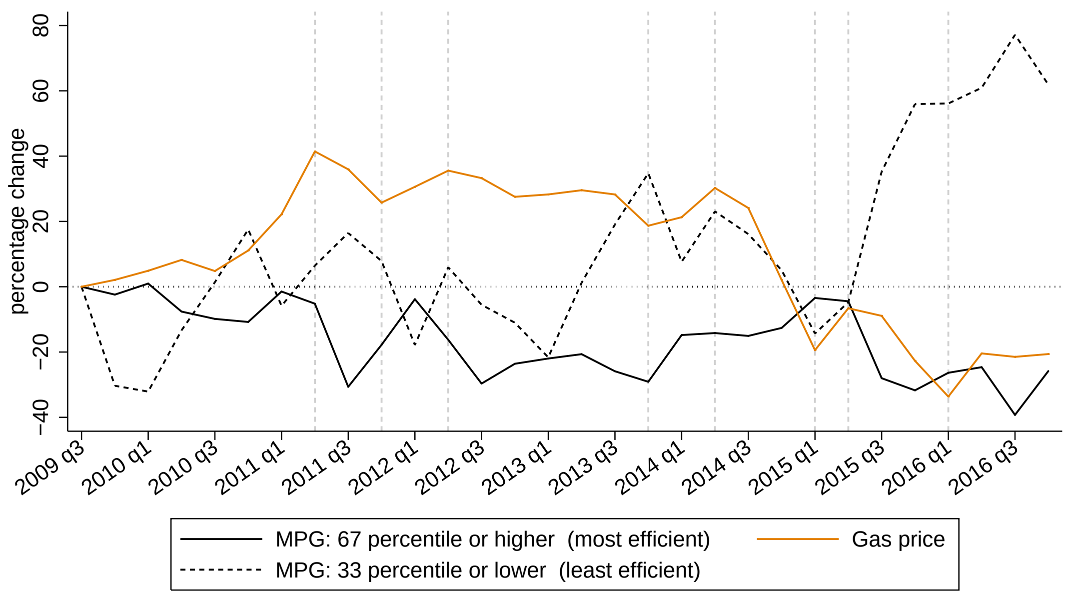


Figure A.2: **Gasoline Prices and Fleet and Retail Average Fuel Economy, 2010–2016**

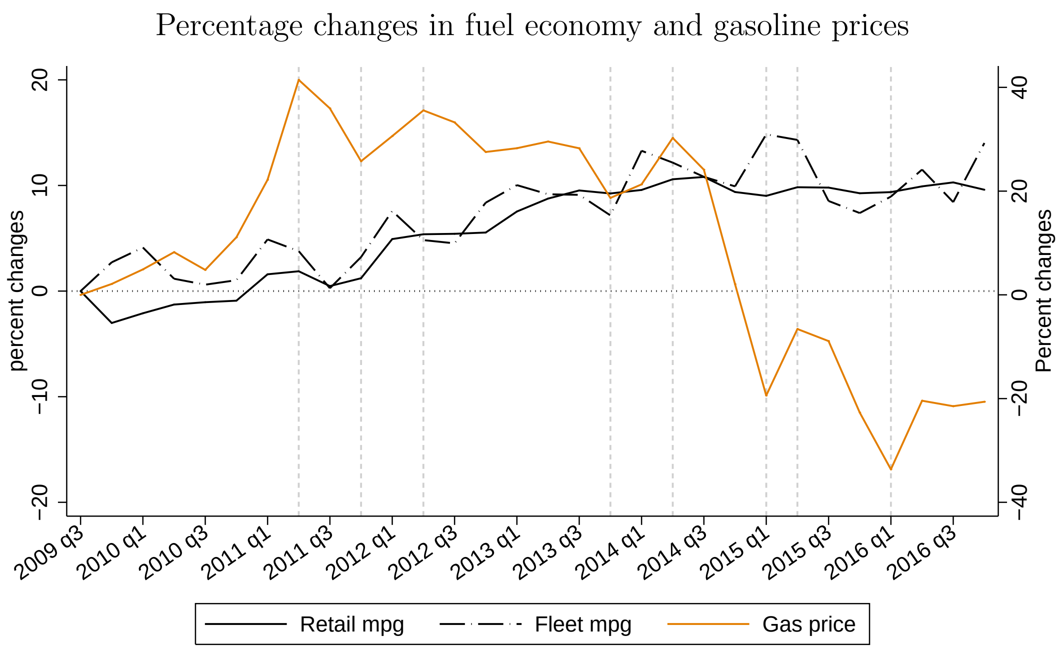
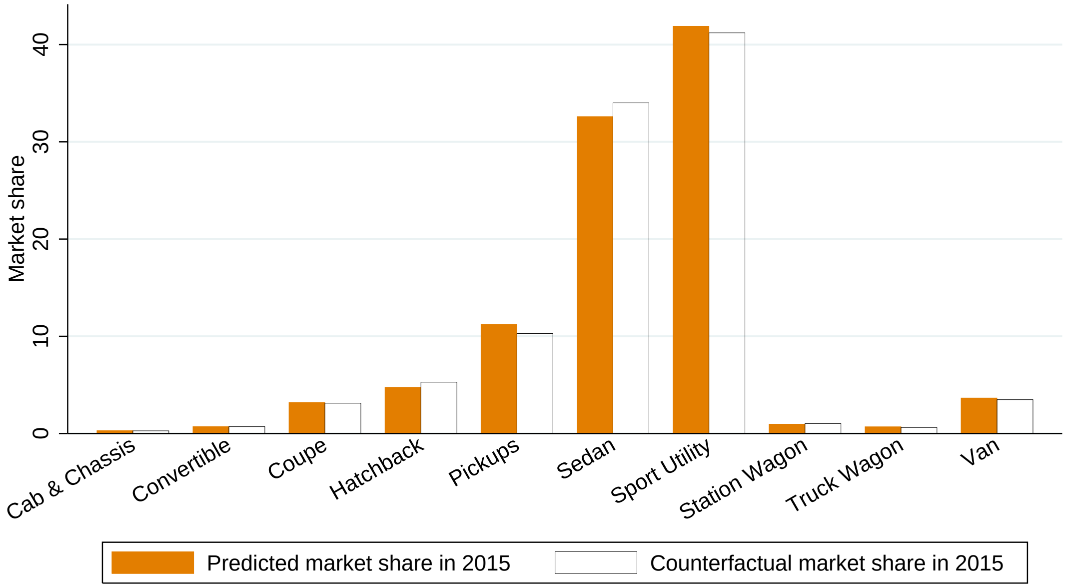
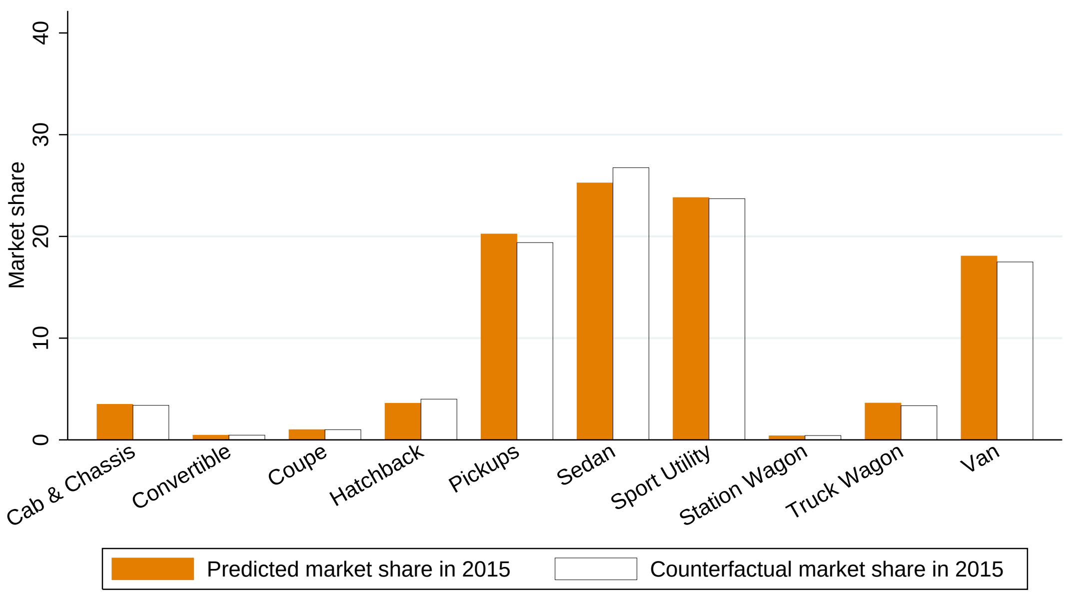


Figure A.3: **Distributional Effects of a $1 Increase in Fuel Price, 2015**

Panel A. Retail vehicles

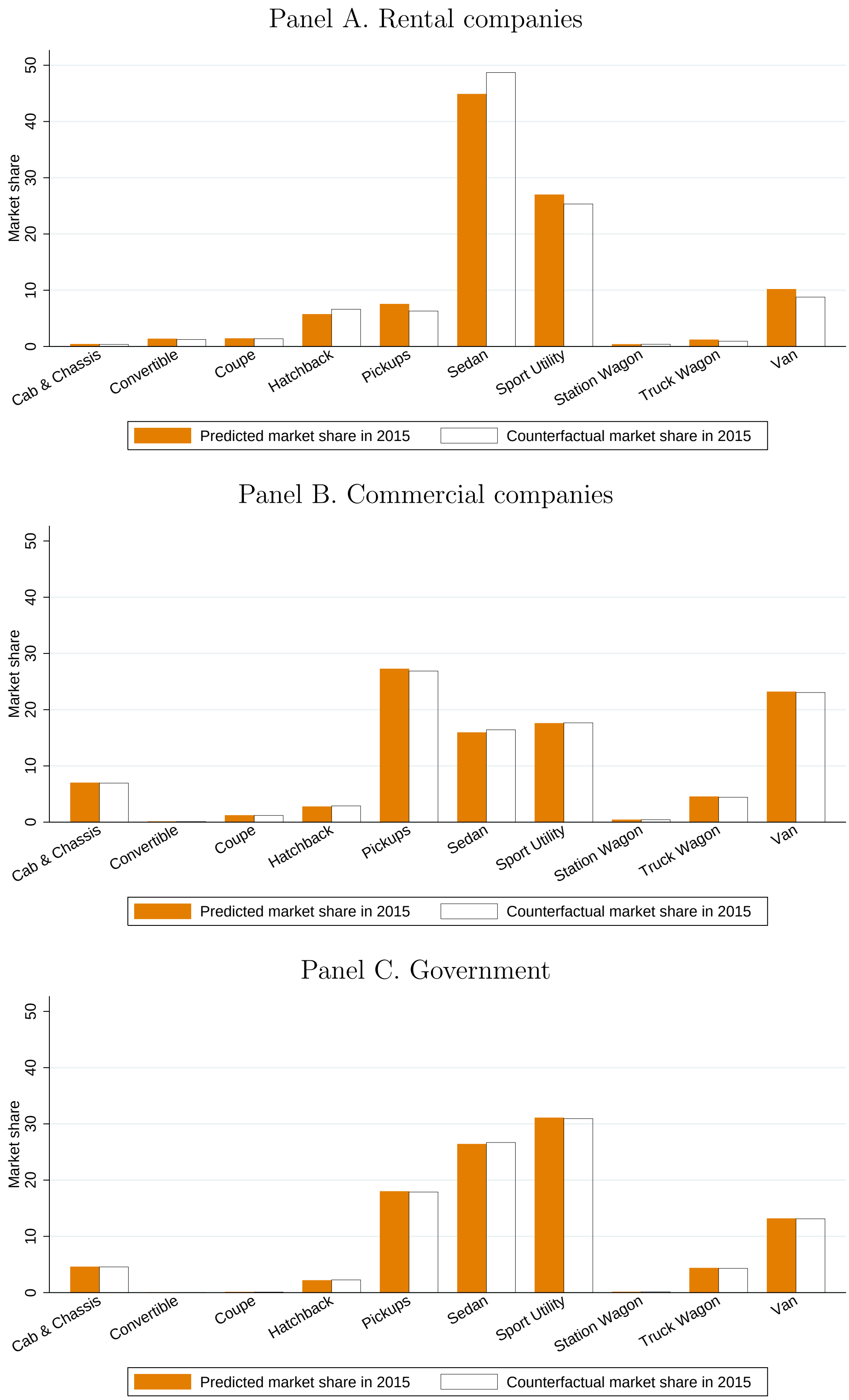


Panel B. Fleet vehicles



Note: 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.)

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



Note: 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.)

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-square	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) Retail	(2) Fleet
fuel cost (dollar-per-mile)	-7.391***	-5.911**
	(2.342)	(2.342)
Number of observations	77,874	67,923
R-square	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 (dollar-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-square	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 by 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.