Pain at the Pump:
How Gasoline Prices Affect Automobile Purchasing[*]

Meghan R. Busse

Northwestern University and NBER

Christopher R. Knittel

University of California, Davis and NBER

Florian Zettelmeyer

Northwestern University and NBER

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Abstract

In this paper we make use of detailed, transaction-level data on automobile purchases and monthly, ZIP-code level data on retail gasoline prices to investigate the effect of fuel prices on four aspects of automobile purchasing in the U.S.: market shares, new car prices, trade-in utilization, and new car inventories. We find statistically and economically significant effects in all four aspects, all of which point to consumers being responsive to gasoline prices in their car choices. Among our results, we find that gasoline price increases lead to overall increased market share for fuel efficient cars and decreased market share for fuel inefficient cars, but that there are also significant market share shifts within car segments. We find that transactions prices of fuel efficient cars rise when gas prices increase, while prices of fuel inefficient cars fall. We find that customers buy more fuel efficient new cars relative to their trade in cars when gas prices increase, and that the trade-in of fuel inefficient cars is accelerated when gasoline prices increase, while the trade-in of fuel efficient cars is delayed. Finally, we find substantial effects on inventories: fuel inefficient cars sit on dealer lots longer when gasoline prices rise, while fuel efficient cars are sold more quickly.

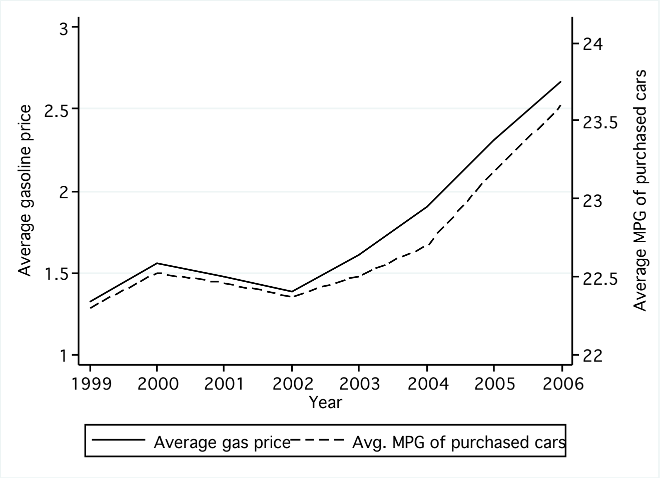
1 Introduction

There are many areas of human activity that affect climate change. One of the largest contributors is transportation. The U.S. EPA estimates that 20% of U.S. CO_2 emissions come from passenger cars and light duty trucks alone. One of the policies that has been suggested as a way to reduce greenhouse gas emissions from the transportation sector is either a tax on gasoline, or a more general carbon tax, which would raise the prices of gasoline and of other energy sources. In order to reduce greenhouse gas emissions, such a tax would have to either reduce how much people drive, or cause them to substitute more fuel efficient vehicles for the vehicles they are currently driving. This paper focuses on the second avenue by investigating the effect of gasoline prices on sales of new automobiles.

While the effect on climate change is one important motivation for understanding the effects of gasoline prices on automobile sales, it is not the only one. The relationship also matters for automobile manufacturers. How responsive manufacturers think customers are to gasoline prices has driven manufacturer product design strategies around size, power and fuel efficiency, and has also influenced their opposition (especially on the part of U.S. manufacturers) to the tightening of CAFE standards. It has also influenced the competitiveness of U.S. auto manufacturers vis-a-vis foreign manufacturers, both in the 1970s, during the first energy crisis, and in the last several years as gasoline prices have risen from $2 per gallon to closer to $4. In May 2008 the Honda Civic edged out the Ford F150 pickup truck as the best selling car in the U.S., a position the pickup truck had held continuously since 1991 (Automotive News, 6/5/2008).

Before we begin describing our empirical approach and data, we offer two graphs that are suggestive of our final story. The first graph, presented in Figure 1, shows the annual average fuel efficiency of cars sold in the U.S. and annual average gasoline prices. Specifically, the solid line shows the average gasoline price in the U.S. between 1999 and 2006, measured in dollars per gallon and scaled on the left axis. The price remained close to $1.50 per gallon between

Figure 1: Average MPG of available cars by model year

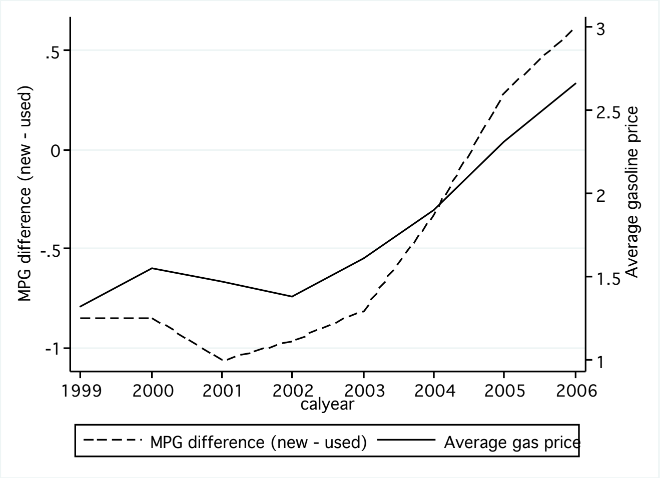


1999 and 2002, and then began to rise steadily through 2006. The dashed line in the same figure graphs the sales-weighted average miles per gallon (MPG) of new cars purchased in the U.S. each year. The MPG scale is reported on the right axis. The two lines track each other quite noticeably. Average miles per gallon hovers around 22.3 between 1999 and 2002, and then begins to climb steadily, reaching 23.6 by 2006.

The second figure makes use of our car purchase data, described in more detail in Section 3, to make a within-customer comparison of car purchases. We observe individual automobile transactions, and observe not only the new car purchased, but also the trade-in used, if any. Using the subset of transactions that do involve trade-ins, we calculated the difference between the MPG of the new car and the MPG of the trade-in car. We then graph the average of this difference every year in the dashed line in Figure 2. The solid line in Figure 2 is the same average gasoline price graphed in Figure 1. The MPG difference line shows that, between 1999 and 2002, a new car buyer bought a new car that had on average lower fuel efficiency (by about 0.75 to 1 MPG) than the car that the customer brought to trade in. Starting around 2003, however, that difference begins to shrink, until by 2005 and 2006, customers are buying new cars that are more fuel efficient (by about 0.5 MPG) than their trade-in cars.

While these graphs are suggestive, we investigate these relationships more formally by

Figure 2: MPG difference between new cars and trade-ins



using detailed data on individual new car transactions and monthly ZIP code level data on retail gasoline prices to investigate the effect of fuel prices on four aspects of U.S. automobile purchasing. We first examine how gasoline prices affect the market shares of different car segments, and of cars of varying levels of fuel efficiency. We find that a \$1 increase in gasoline prices increases the market share of the most fuel efficient quartile of cars by 15.1% and decreases the market share of the least fuel efficient quartile by 11.5%. Next, we investigate the effect of fuel prices on the transaction prices of new cars. We find that when gasoline prices increase by \$1, the transaction price of the most fuel efficient cars increase by \$49 on average, while the transaction prices of the least fuel efficient cars falls by \$325. Third, we investigate how changes in fuel prices affect the utilization of trade-ins by buyers of new cars. We find that a \$1 increase in gasoline prices increases the average difference between the EPA miles per gallon (MPG) rating of a new car and the car traded-in in the same transaction by 1.02 MPG, meaning that customers choose more fuel-efficient new cars relative to their trade-in cars. Also, we find that a \$1 increase in gasoline prices decreases the average age of a trade-in in the least fuel efficient quartile by 1 year, while increasing the average age of a trade-in in the most fuel efficient quartile by 0.8 year, which suggests that customers are accelerating trade-ins of fuel inefficient cars while delaying the trade-in of fuel efficient cars. Finally, we investigate the effect of fuel prices on inventories of new cars. Our data enable us to observe inventory levels at new car dealers. We find that a \$1 increase in gasoline prices increases the days a fuel inefficient car spends on the dealer lot by 11.2 days, an 18% change relative to the average time for such cars, while the same increase leads to a decrease in the number of days a fuel efficient car spends on the lot by 9.6 days, a 21% decrease relative to the average for these cars.

There is a long-standing literature investigating the determinants of automobile sales. (The earliest papers we have found pre-date World War II.) There is also a large literature, dating from the first energy crisis that investigates the relationship between fuel efficiency and gasoline prices. Our paper is also related to more recent literatures on automobile demand estimation, and on the role of gasoline prices in car choices. Our results with respect to market shares are closely related to estimation of demand for automobiles. A number of discrete choice demand models exist for which mileage, or an estimate of dollars per mile, is a characteristic in the indirect utility function.[1] Typically, the influence of gasoline prices is not the focus of these papers. Two exceptions are Klier and Linn (2008) and Sawhill (2008). Klier and Linn (2008) estimate an aggregate data logit model using monthly sales data from 1970 to 2007. Consistent with our results, they find that fuel economy increases by 1.08 MPG for a dollar increase in gas prices. Sawhill (2008) estimates the implicit discount rate that consumers use when trading off upfront costs with future fuel costs. Using aggregate market share data, he finds significant heterogeneity in this utility parameter; however it is uncertain whether the heterogeneity is also measuring the variation in miles driven across consumers.[2] Langer and Miller (2008) capture one component that is related to our price results. They look at how automobile incentives respond to gasoline prices. They have data on listed rebates and incentives, but do not observe the extent to which consumers take advantage of these incentives or how they are shared between consumers and dealers.

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[1] For example, see such seminal papers as Goldberg (1995) and Berry, Levinsohn, and Pakes (1995).

[2] Sawhill (2008) has data on the distribution of miles driven across the population which allows him to match a population moments, however is not able to match correlations between a consumer's discount rate and miles driven.

Our paper contributes to the existing literature in two ways. First, we have detailed, individual-level transaction data on new car purchases, and monthly, ZIP code level retail prices for gasoline. This allows us to exploit both longitudinal and cross-sectional variation in gasoline prices to identify our primary effects of interest. Second, we are able to look at many more facets of automobile purchasing than previous literature has. We can investigate the effects on market share controlling for a number of factors that might influence individual negotiations. We can investigate the effect on prices using actual transactions prices, that take into account negotiations, trade-in payments, etc. Furthermore, we can investigate the effect on trade-in utilization, which allows us to compare to some extent customers' choices over time. Finally, we can investigate what happens to inventories for automobiles, giving us some insight into whether and how the automobile supply chain can respond to changes in gasoline prices.

This paper proceeds as follows. In the next section, we describe the general empirical approach that we will use in this paper. In Section 3, we describe the data used in the paper. Section 4 is the main body of the paper. It describes the exact empirical specifications, and the exact data used to investigate the effect of fuel price on each of the four aspects of automobile purchasing that we described above, and reports the results of those estimations. Section 5 describes several extensions, and Section 6 concludes.

2 Empirical approach

Our approach in this paper will be to investigate the effect of gasoline prices on both prices and sales of new automobiles. The reason for investigating both arises from institutional features of the automobile industry. Automobile production is a relatively inflexible manufacturing technology. Although there are some exceptions, most plants are designed to produce only one type of vehicle, making switching production from a low fuel-efficiency SUV to a high-fuel efficiency compact car impossible in most circumstances. Second, many costs of production are incurred whether a plant operates or not. Most notably, for many manufacturers, a large fraction of the labor expense will be incurred whether auto workers are producing cars or not. Production is not completely inflexible, however. Inventory carrying costs are high for automobiles, and manufacturers will choose not to produce cars they think are sufficiently unlikely to sell. In a 1994 article, Bresnahan and Ramey found that on average, auto plants are shut down for almost seven weeks per year. While some of this is for model changeover, or accidental events such as fires, Bresnahan and Ramey estimate that 25-50% of the plant closures are for inventory adjustments.

These institutional characteristics lead most manufacturers to have a two-tiered response to demand decreases. Manufacturers tend to respond first, or to respond to small decreases in demand, with lower prices (often via rebates to either dealers or end-customers). For persistent or large decreases in demand, manufacturers respond with output reductions.

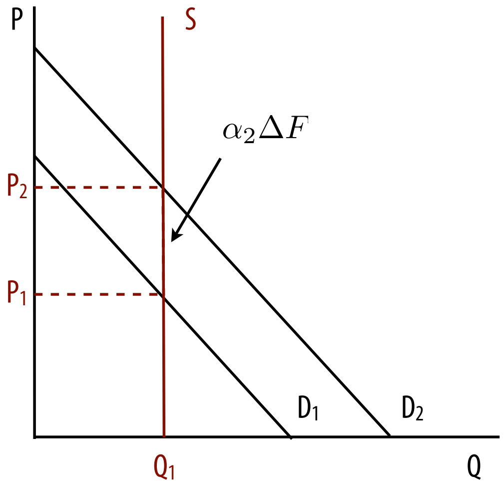
We will estimate these two effects using reduced form models of the effect of gasoline prices on new car prices and on new car sales (which we will measure as shares). This approach raises two natural questions. First, what is the reduced form estimating in this case? Second, why are we not estimating a structural model of demand?

We address the first question first. To crystallize ideas, suppose that the inverse demand for a particular car model i at time t is given by

$$P_{it} = \alpha_0 + \alpha_1 Q_{it} + \alpha_2 F_t + \boldsymbol{\alpha_3 X_{it}} + \epsilon_{it}, \tag{1}$$

where P_{it} is the new car price, Q_{it} is the unit sales of the new car, F_t is the price of gasoline, and X_{it} are car characteristics and time varying effects (such as how old the model is). An increase in F, the price of gasoline, will increase the costs of operation of all cars. However, if demand for car transportation as a whole is fairly inelastic, then the total number of vehicles might well be little changed. The effect of an increase in F then would be to increase demand for fuel-efficient cars and decrease demand for fuel-inefficient cars. This would mean that α_2 would be greater than zero for fuel-efficient cars, and α_2 would be less than zero for fuel-inefficient

Figure 3: Automobile market with perfectly inelastic supply



cars.

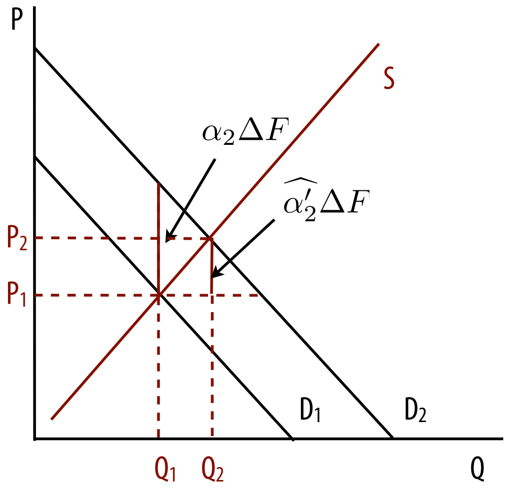
Suppose that supply happened to be perfectly inelastic, as depicted in Figure 3. Consider what would happen if F were to increase by ΔF. In that case, customer willingess-to-pay would change by $\alpha_2\Delta F$ (Figure 3 shows this an an increase, inplying that the hypothetical car depicted in the figure is relatively fuel efficicient). In the case of perfectly inelastic demand depicted in Figure 3, the observed price increase would also equal $\alpha_2\Delta F$. If we were to estimate the reduced form (leaving out Q_{it}) given by

$$P_{it} = \alpha_0^{'} + \alpha_2^{'} F_t + \boldsymbol{\alpha_3^{'} X_{it}} + \epsilon_{it}^{'} \tag{2}$$

then $\hat{\alpha}_2^{'}\Delta F$ would consistently estimate $\alpha_2\Delta F$. In other words, the coefficients of the demand covariates could be estimated by estimating the reduced form.

While inelastic supply would be a convenient special case, what would we have estimated by estimating Equation 2 if the supply curve had some elasticity? As Figure 4 illustrates, $\hat{\alpha}_2^{'}\Delta F$ would now estimate the change in the *short run equilibrium price* in response to a gasoline price increase of ΔF. This would not be the same as the change in *willingness-to-pay* in response to a gasoline price change of ΔF. However, what we are interested in esimating in

Figure 4: Automobile market without perfectly inelastic supply



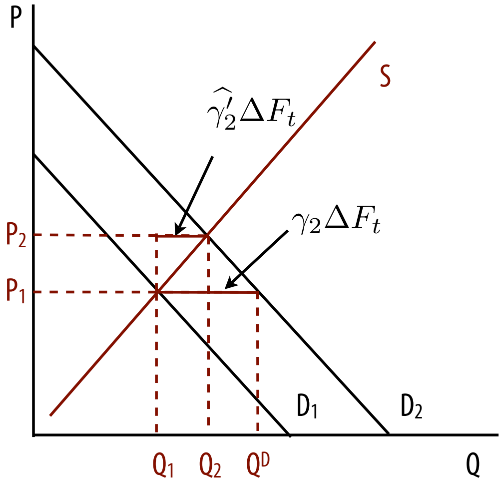
this paper is indeed the changes in equilibrium prices (and quantities, to which we will turn next), not in willingness-to-pay. This is because, for the climate policy implications of this work, what we are interested in knowing is how gasoline prices affect the vehicles that actually appear on the road *after* we allow manufacturers and dealers to respond to the gasoline price change. Estimating the effect on willingness-to-pay would estimate the effect if manufacturers and dealers were not allowed to repond. While this would, of course, be the correct input for various simulations or counterfactual scenarios, in this paper our aim is to estimate what the observed short run equilibrium effect of fuel changes was, including the effect of whatever supply response a gasoline price change prompts.

A very similar logic applies to our approach to estimating the effect of gasoline prices on quantity. We can transform the inverse demand curve in Equation 1 to the demand curve given below by Equation 3.

$$Q_{it} = \gamma_0 + \gamma_1 P_{it} + \gamma_2 F_t + \boldsymbol{\gamma_3} \boldsymbol{X_{it}} + \xi_{it} \tag{3}$$

Based on this equation, $\gamma_2 \Delta F$ can be interpreted as the effect of a change in gasoline prices of ΔF on the quantity of new cars demanded if new car prices were to remain unchanged. Figure 5 illustrates this effect graphically.

Figure 5: Automobile market model



We now consider estimating the reduced form of the demand curve (leaving out P_{it}) given by

$$Q_{it} = \gamma_0' + \gamma_2' F_t + \boldsymbol{\gamma_3' X_{it}} + \xi_{it}'. \tag{4}$$

The estimate from this equation of $\hat{\gamma}_2' \Delta F$ would estimate $\gamma_2 \Delta F$, which is the short run equilibrium effect on the quantity of cars sold as a result of a gasoline price increase. This does not estimate the change in the quantity demanded, prices held constant, but it is in fact the change in the transaction quantity that we want to estimate in this paper, making this the appropriate object of our estimation strategy.

Although we have been careful in this section to note that the object of our approach is an estimate of the short-run effects of fuel prices, it is worth noting explicitly that this leaves out effects that are interesting to the ultimate question of transportation effects on climate change with which we motivated this paper. In the concluding remarks we discuss in more detail how our results fit into answering this larger question. Here we simply note that there are long-run effects that would likely occur (such as a change in the portfolio of cars that manufacturers chose to offer), that are interesting and important, but which are beyond the scope of this paper to answer.

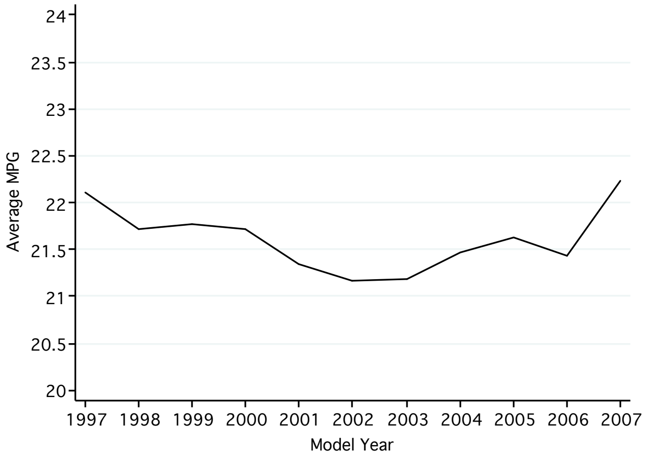
3 Data

We have combined several types of data for this analysis. Our main data contains automobile transactions from a sample of 15-20% of all dealerships in the U.S. from September 1, 1999 to June 30, 2006. The data were collected by a major market research firm, and include every transaction within the time period for the dealers in the sample. For each transaction we observe the exact vehicle purchased, the price paid for the car, the dealer's cost of obtaining the car from the manufacturer, information on any trade-in vehicle used, and (census-based) demographic information on the customer. We will discuss in detail the variables used in our specification later in the paper.

We have supplemented these transaction data with data on car models' fuel consumption and data on gasoline prices. The fuel consumption data is from the Environmental Protection Agency (EPA). We define the fuel consumption of each car model as the average of the EPA Highway and City Vehicle Mileage. As shown in Figure 6, the average MPG of models available for sale in the United States showed a pattern of general–although not monotonic–decline between 1999 and 2006, the sample period of our transaction data. While *cars* became less fuel efficient over this period, this does not mean that *engines* became less fuel efficient. The average horsepower of available models increased substantially over sample years, a trend that pushes toward higher fuel consumption.

The gasoline price data are from OPIS (Oil Price Information Service) and cover January 1997 to December 2007. OPIS obtains gasoline price information from credit card and fleet fuel card "swipes" at a station level. We purchased monthly station level data for stations in 15,000 ZIP codes. Ninety eight percent of all new car purchases in our transaction data are made by buyers who reside in one of these ZIP codes. We create monthly ZIP-code level gasoline prices by averaging the prices for basic grade over all stations in each ZIP code. As shown in Figure 7, there is substantial variation in gasoline prices in our sample period. Between 1999 and 2006 average national gasoline prices were as low as \$1 and as high as \$3. While gasoline prices were

Figure 6: Average MPG of available cars by model year



generally trending up during this period there are several months where gasoline prices were lower than in months prior.

There is also substantial regional variation in gasoline prices. The left hand side of Figure 8 illustrates this by comparing California and Louisiana average monthly gasoline prices (with the national average as a reference). Not only are California gasoline prices substantially higher than prices in Louisiana, there is also variation in how much higher California prices are. There is also substantial dispersion of gasoline prices within states. The right hand side of Figure 8 shows the distribution of monthly gasoline prices in California.

More formally, to understand how much of the variation in gasoline prices come from regional variation as opposed to variation over time, we decompose the standard deviation into between and within components. The overall mean of gasoline prices between January 1999 and June 2006 is \$1.69. The overall standard deviation is 0.48 whereas the "between" standard deviation is 0.23 and the "within" standard deviation is 0.46. A second approach to assess the variation in the data is to calculate (1) for each ZIP code in the sample the standard deviation of gasoline prices across months and (2) for each month in the sample the standard deviation of gasoline prices across ZIP codes. Figure 9 shows a histogram of the two sets of standard deviations. The figure suggests that while more variation in the gasoline data occurs over time,

Figure 7: Monthly national average gasoline prices

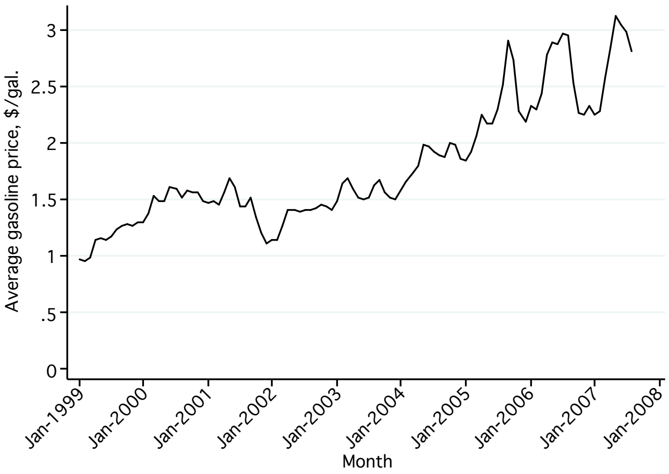


Figure 8: Examples of gasoline prices variation

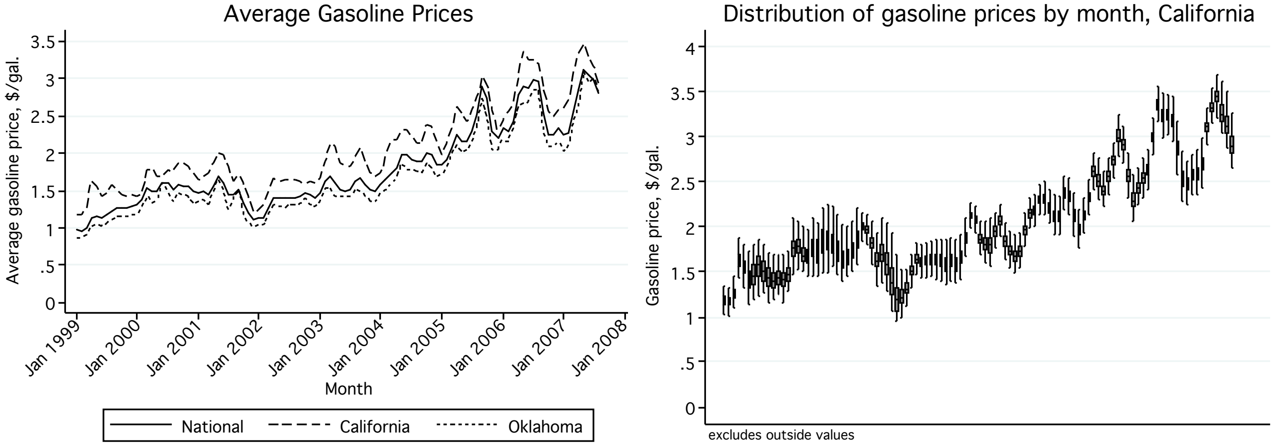
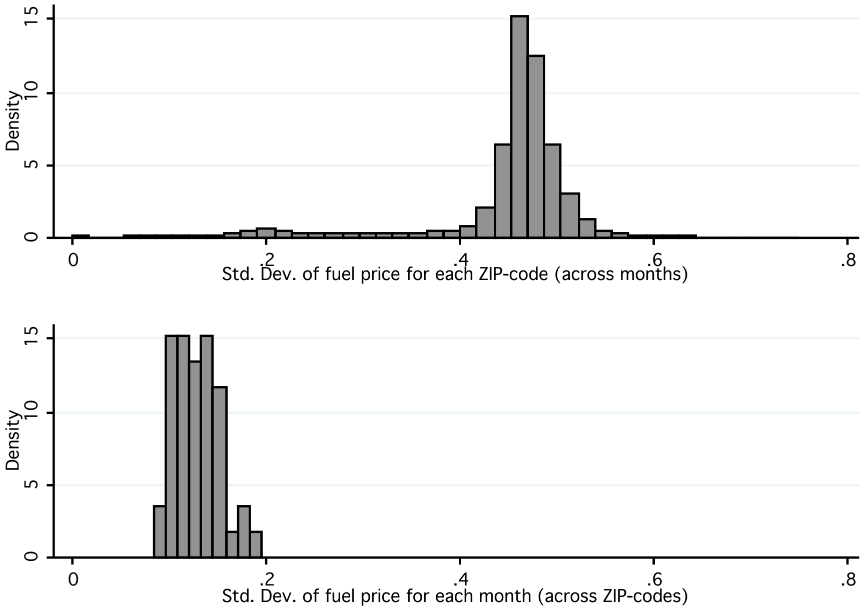


Figure 9: Variation in gasoline prices across and within region



there is also substantial geographic variation.

To create our final dataset we choose a 10% random sample of all transactions. After combining the three datasets this leaves us with 1,368,312 observations. Table **??** presents summary statistics for the data.

4 Specifications and Results

Our analysis will focus on the effect of gasoline prices on four distinct measures of outcomes in the new car industry: sales, prices, trade-ins, and inventories.

4.1 Sales

We first investigate the effect of gasoline prices on new car sales.

4.1.1 Specification and variables

We use market share as a sales outcome variable rather than unit sales because this controls for the substantial aggregate fluctuation in car sales over the year. Specifically we estimate a series of linear probability models with the following specification:

$$I_{irt}(j \in K) = \gamma_0 + \gamma_1 \text{GasolinePrice}_{it} + \gamma_2 \text{Demog}_{it} + \gamma_3 \text{PurchaseTiming}_{jt} + \delta_j + \tau_t + \mu_{rt} + \epsilon_{ijt} \quad (5)$$

$I_{irt}(j \in K)$ is an indicator that is 1 if transaction i in region r on date t for car type j was for a car in class K. We will consider a series of different classes in this section, namely fuel efficiency quartiles, segments (e.g midsize, SUV, compact), and subsegments (e.g. entry compact, premium compact, mini SUV, compact SUV). The variable of primary interest is *Gasoline Price*, which is specific to the month in which the vehicle was purchased and to the ZIP code of the buyer.

We use an extensive set of controls. First, we control for a wide range of demographic variables (Demog_{it}), namely the income, house value and ownership, household size, vehicles per household, education, occupation, average travel time to work, English proficiency, and race of buyers by using census data at the level of "block groups," which, on average, contain about 1100 people.[3] Next we control for detailed characteristics of the vehicle purchased by including "car type" fixed effects (δ_j). A "car type" in our sample is the interaction of model year, make, model, trim level, doors, body type, displacement, cylinders, and transmission (for example, one car type in our data is a 2003 Honda Accord EX 4 door sedan with a 4 cylinder 2.4 liter engine and automatic transmission). We also account for a series of variables that describe purchase timing ($\text{PurchaseTiming}_{jt}$). These variables include: a dummy variable

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[3] One might argue that our specification should not hold the demographics of buyers constant for the following reason: Any change in market shares of fuel efficient vs. fuel inefficient cars due to changes in demographics associated with fuel price changes can legitimately be considered to be part of the short-run equilibrium sales effect of changing gasoline prices. Therefore we have estimates all of our sales specifications without demographic covariates and find that our results are robust to the exclusion of the demographic variables.

EndOfYear that equals 1 if the car was sold within the last 5 days of the year; a dummy variable *EndOfMonth* that equals 1 if the car was sold within the last 5 days of the month; a dummy variable *WeekEnd* that specifies whether the car was purchased on a Saturday or Sunday. If there are volume targets or sales on weekends, near the end of the month or the year, we will pick them up with these variables. Our purchase timing variables also include a control for the number of months between when the model of the vehicle's model year was introduced and when the particular vehicle was sold. This proxies for how new a car design is and also for the dealer's opportunity cost of not selling the car. Finally, we control for the year in (τ_t),[4] and the month of the year (μ_{rt}) in which the purchase was made. We allow the latter to vary by the geographic region (29 throughout the U.S.) in which the car was sold. This takes into account that the seasonal preference for specific car classes may vary by region of the country.

The controls we have specified here we have motivated as "demand" controls, not "supply" controls. This means that our estimate of γ_1 will be a compound of the effect of gasoline prices on the demand for automobiles and the effect of gasoline prices (if any) on the supply of automobiles. Gasoline is, in fact, not a particularly significant input into the manufacture of automobiles, so one might believe that direct supply effects are likely to be small. Of course, one reason gasoline prices fluctuate is because of fluctuation in oil prices. Oil is, to some extent, an upstream input of cars (through plastics, for example). However, this may also not be a significant effect. This is because short to medium-run manufacturing and pricing decisions for automobiles are not, in practice, made on the basis of manufacturing costs. While we realize that almost any model of profit maximization an economist would write down would certainly suggest that pricing and production ought to depend on costs, our interactions with executives responsible for these decisions at car manufacturers indicate that this is not the way short to medium-run pricing and manufacturing decisions are made in practice.

In Section 2, we argued that in this paper we wished to estimate the effect of fuel prices on

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[4] We have also estimated the linear probability models replacing the fixed year effects with a second order polynomial time trend; the results are extremely similar to those presented in the paper.

the equilibrium prices and quantities of cars, motivating this notion with a simple graph that included the movement along the supply curve in our estimated effect. If, for some reason, the supply curve is shifting because of changes in fuel price, the net effect, including the supply shift, is what we will measure.

4.1.2 Sales results

We first consider the effect of gasoline prices on the market shares of different classes of gasoline efficiency. Specifically, we classify all transactions in our sample by the fuel efficiency quartile (based on the average of the city and highway EPA MPG ratings for each model) of the purchased car type. Quartiles are defined based on the distribution of all models offered between 1999 and 2006.

	MPG $>$	MPG $\leq$	Mean
MGP Quartile 1	0	17.7	16.1
MPG Quartile 2	17.7	21.2	19.5
MPG Quartile 3	21.2	24.3	23.0
MPG Quartile 4	24.3	∞	28.4

We first estimate Equation 5 with car class defined by MPG quartile. To do this, we define four different dependent variables. The dependent variable in the first estimation is “1” if the purchased car is in fuel efficiency quartile 1, “0” otherwise. The dependent variable in the second estimation is “1” if the purchased car is in fuel efficiency quartile 2, “0” otherwise, and so on.

The estimates of the gasoline price coefficient (γ_1) for each estimation are presented below.[5] We also report the standard errors of the estimates, and the average market share of each MPG quartile in the sample period. Combining information in the first and third column, we report in the last column the percentage change in market share that the estimated coefficient implies would result from a \$1 increase in gasoline prices. Figure 10 repeats the finding graphically.

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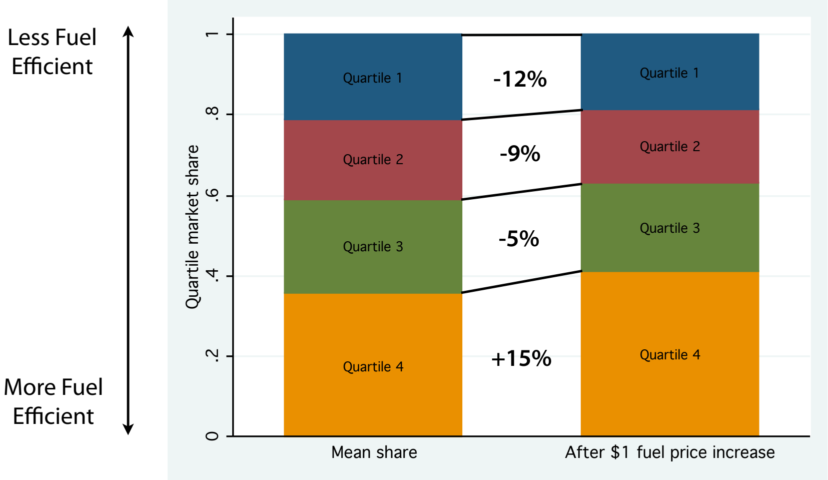
[5] See Table 2 on page 40 for the full estimation results.

Fuel Efficiency	Coefficient	SE	Mean share	% Change in share
MPG Quartile 1 (least fuel efficient)	-0.024**	(0.006)	21.0%	-11.5%
MPG Quartile 2	-0.018**	(0.006)	20.0%	-9.0%
MPG Quartile 3	-0.011*	(0.004)	23.3%	-4.7%
MPG Quartile 4 (most fuel efficient)	0.054**	(0.010	35.7%	15.1%

Figure 10: Change in fuel efficiency quartile shares



These results suggest that a \$1 increase in gasoline price will decrease the market share of cars in the least fuel efficient quartile by 2.4 percentage points, or 11.5%. Conversely, we find that a \$1 increase in gasoline price will increase the market share of cars in the most fuel efficient quartile by 5.4 percentage points, or 15.1%. This provides evidence that higher gasoline prices are associated with the purchase of more fuel efficient cars. Notice that these estimates do not simply reflect an overall trend of increasing gasoline prices and increasing fuel efficiency; since we control for year fixed effects, all estimates rely on within-year variation in gasoline prices and associated purchases.

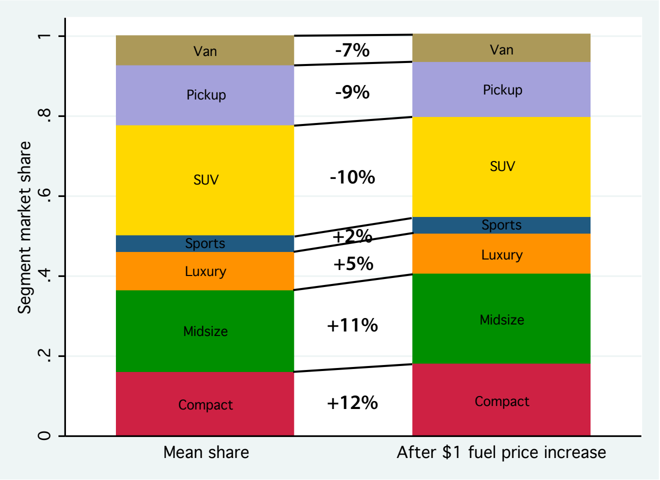
Next we consider the effect of gasoline prices on the market shares of different car classes as defined by industry segments. The industry uses a standard classification of eight segments: “Compact Car” (e.g. Toyota Corolla), “Luxury Car” (e.g. Lexus LS430), “Midsize Car” (e.g. Honda Accord), “Pickup” (e.g. Ford F150), “Sport Utility Vehicle (SUV)” (e.g. Jeep Grand Cherokee) “Sporty Car” (e.g. Mitsubishi Eclipse), “Van” (e.g. Toyota Sienna) , and “Fullsize

Car" (e.g. Ford Crown Victoria).[6] We estimate the specification in Equation 5 for each of seven segments (we exclude fullsize cars since very few of them are sold). The dependent variable in the first estimation is "1" if the purchased car is a "Compact Car", "0" otherwise. We proceed similarly for the other segments.

The relevant estimates of the fuel price coefficient from these specifications are presented below.[7] In addition to the coefficient estimates, the table reports the standard errors and the average market shares of each segment over the sample period. The last column of the table presents the percent change in market share of each segment implied by a $1 increase in gasoline prices. Figure 11 depicts the results graphically.

Segment	Coefficient	SE	Mean Mkt Share	% Change in Share
Compacts	0.019**	(0.005)	16.4%	11.6%
Midsize	0.022**	(0.004)	20.3%	10.8%
Luxury	0.005	(0.004)	9.5%	5.3%
Sporty Cars	0.001	(0.001)	4.2%	2.4%
SUVs	-0.027**	(0.010)	27.6%	-9.8%
Pickups	-0.013**	(0.004)	14.8%	-8.8%
Vans	-0.005**	(0.001)	7.2%	-6.9%

Figure 11: Predicted change in segment market shares



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[6] See Table 1 for more examples of cars in each segment.

[7] See Table 3 on page 41 for the full estimation results.

These results show an inflow of consumers into compact and midsize cars (which on average have high fuel efficiency, see Table 1) and an outflow of consumers from SUVs and pickups (which on average have low fuel efficiency, see Table 1). The market share of vans is also decreasing. Overall there is a meaningful shift in the composition of segment shares in response to a gasoline price change that is well within the magnitude of changes seen in the last decade.

We find no statistically significant effect for luxury or sporty cars. We can think of several reasons for this finding. One possibility is that luxury and sporty cars both gain and lose as a result of gasoline price changes. For example, one could imagine that some buyers opt for a luxury sedan instead of a luxury SUV if gasoline prices increase, while others substitute from a luxury sedan to a more economical midsize car in response to the same gasoline price increase. An alternative explanation is that fuel efficiency is simply not a decision criterion for the purchase of luxury cars and sporty cars, or that buyers who buy such cars are fairly insensitive to the price of gasoline, perhaps because they are wealthier than the average car buyer.

Finally, we look at a finer classification of cars. Specifically, we split each segment into two to four subsegments according to the standard industry definition of a subsegment (see Table 1 for a list of subsegments and examples of cars in each subsegment). This allows us to check whether gasoline price increases affect all cars in a segment equally. One might expect that it should not. For example, the pickup category contains both fuel efficient compact pickups (e.g. Ford Ranger) and fuel inefficient full-size trucks (e.g. Ford F250 Heavy Duty).

We estimate Equation 5 for each of 18 subsegments (we exclude full size cars since very few of them are sold). The dependent variable in the first estimation is “1” if the purchased car is a “Entry Compact Car”, “0” otherwise. We proceed similarly for the other subsegments.

The estimates of the fuel price coefficients, their standard errors, and the mean market shares of each subsegment are presented below.[8] As in the previous two tables, the last column

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[8] See Table 4 on page 42 for the full estimation results.

reports the percent change in market share of each subsegment implied by a $1 increase in gasoline prices.

Subsegment	Coefficient	SE	Mean Mkt Share	% Change in Share
Entry Compact	0.005**	(0.001)	1.13%	44%
Premium Compact	0.014**	(0.005)	15.20%	9%
Lower Midsize Car	0.005*	(0.002)	3.77%	13%
Upper Midsize Car	0.015**	(0.004)	15.98%	9%
Near Luxury Car	0.003	(0.002)	6.06%	5%
Traditional Luxury Car	0.000	(0.001)	0.98%	0%
International Luxury Car	0.003	(0.002)	2.71%	11%
Entry Sporty Car	0.000	(0.000)	0.33%	0%
Middle Sporty Car	-0.001	(0.001)	2.99%	-3%
Premium Sporty Car	0.001	(0.001)	1.24%	8%
Mini SUV	-0.003	(0.003)	6.62%	-5%
Compact SUV	-0.009+	(0.005)	13.52%	-7%
Fullsize SUV	-0.012**	(0.002)	4.47%	-27%
Luxury SUV	-0.003	(0.003)	3.46%	-9%
Compact Pickup	0.006*	(0.003)	4.98%	12%
Fullsize Pickup	-0.019**	(0.003)	9.34%	-20%
Compact Van	-0.006**	(0.002)	6.85%	-9%
Fullsize Van	0.000	(0.000)	0.36%	0%

This analysis reveals interesting variation that was obscured by the analysis based on the coarser segment classification. Starting with compact cars, we find that the sales of all subsegments increase, however, the increase in market share for premium compacts, which is 1.4 percentage points, is greater than that of entry compacts, whose market share rises by 0.5 percentage points (entry compacts experience the biggest change relative to their average market share of all the subsegments, although this is largely because the subsegment is such a small one). We speculate that this may be driven by buyers substituting away from midsize cars who might be more likely to switch to a smaller but otherwise comparable vehicle (a premium compact) than to a "starter" car.

We see a similar pattern in midsize cars to what we saw in compact cars. Both midsize subsegments exhibit share increases, but the upper subsegment increases share by 1.5 percentage points compared to 0.5 percentage points for the lower subsegment. We speculate that this may be due to greater inflow into the midsize segment (say from SUVs and pickups) that outflow from the midsize segment (into compact cars), with the inflow more likely to go into the upper midsize segment than the lower midsize segment. We believe this is the pattern we would see if buyers were altering their vehicle choice to obtain higher fuel efficiency, but trying to maintain some of the attributes of the larger, more powerful cars they would otherwise have purchased.

We did not find any statistically significant effect for luxury and sporty cars when we did our segment based analysis, and the finer classification into subsegments yields no further insight. There simply does not appear to be a statistically significant effect of fuel prices in these tho segments.

We find that the larger the SUV, the larger (and more statistically significant) the decrease in market share (the exception are luxury SUVs which behave more like luxury cars than SUVs). The market share of full-size SUVs decreases by 1.2 percentage points (a 28% decrease) in response to a $1 increase in gasoline prices, while the market share of compact SUVs decreases by only 0.9 percentage points (a 7% decrease); the latter result is statistically significant only at the 10% level.

The pickup segment shows what may be the starkest difference subsegments. We find that the market share of full-size pickups decreases by 1.9 percentage points (a 20% decrease), while the market share for compact pickup trucks *increases* by 0.6 percentage points (a 12% increase). This suggests that sizable fraction of pickup truck buyers stay within the pickup truck segments but downgrade to smaller pickup trucks. We speculate that this may be because of very strong taste preferences of pickup buyers to stay within the pickup segment, or perhaps because there are are commercial or recreational uses of full-size pickups for which a compact pickup may substitute, but for which another type of vehicles will not.

Our final finding is that the market share of compact vans (more commonly called minivans) decreases but that of full-size (e.g. airport, commercial) vans does not. One explanation is that there is not a good substitute for commercial vans (or that higher gasoline prices increase demand for vanpools), while consumers can more easily switch from minivans to a car such as a station wagon as a substitute.

4.2 Prices

Next, we investigate the effect of gasoline prices on the transaction prices paid by buyers for new cars.

4.2.1 Specification and variables

The price contained in our dataset is the pre-sales tax price that the customer pays for the vehicle, including factory installed accessories and options, and including any dealer-installed accessories contracted for at the time of sale that contribute to the resale value of the car.[9]

Conceptually, we would like our price variable to measure the customer's total wealth outlay for the car. In order to capture this, we make two modifications to the observed transaction price. First, we subtract off the customer cash amount if the car is purchased under a customer cash rebate since the manufacturer pays that amount on the customer's behalf. Second, we subtract from the purchase price any profit the customer made on his or her trade-in (or add to the purchase price any loss made on the trade-in). The price the dealer pays for the trade-in vehicle minus the estimated wholesale value of the vehicle (as booked by the dealer) is called the *TradeInOverAllowance*. Dealers are willing to trade off profits made on the new vehicle transaction and profits made on the trade-in transaction, which is why the *TradeInOverAllowance* can be either positive or negative. When a customer loses money on the trade-in transaction, part of his or her payment for the new vehicle is an in-kind payment with the trade-in vehicle. By subtracting the *TradeInOverAllowance* we adjust the negotiated (cash) price to include this payment.

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[9] Dealer-installed accessories that contribute to the resale value include items such as upgraded tires or a sound system, but would exclude options such as undercoating or waxing.

Our price specification is as follows:

$$P_{irjt} = \alpha_0 + \alpha_1(\text{GasolinePrice}_{it} \cdot \text{MPG Quartile}_j) + \alpha_2\text{Demog}_{it} + \\ \alpha_3\text{PurchaseTiming}_{jt} + \delta_j + \tau_t + \mu_{rt} + \epsilon_{ijt} \qquad (6)$$

P_{irjt} is the above defined price for transaction i in region r on date t for car j. We are interested in estimating how gasoline prices affect the transaction prices paid for different cars. One might think that since higher gasoline price make car ownership more expensive, higher gasoline prices will lead to lower negotiated prices for all cars. However, this would ignore the results of the previous subsection, which show that as gasoline prices increase, some cars experience sales increases and other decreases. It would thus not be surprising if the transaction prices of the most fuel efficient cars were to increase as a result of a gasoline price increase. To capture this, we estimate separate coefficients for the *Gasoline Price* variable, depending on the quartile into which car j falls within the MPG distribution of cars available for sale in the U.S.

We use the same extensive set of controls we have used in the market share specification (see page 15).

4.2.2 Price results

The full results from estimating the specification in Equation 6 are presented in Table 5. The gasoline price coefficients are as follows:

Variable	Coefficient/SE
MPG Quartile 1 * Gasoline Price (least fuel efficient)	-324.976** (24.665)
MPG Quartile 2 * Gasoline Price	-183.135** (21.787)
MPG Quartile 3 * Gasoline Price	-20.416 (18.222)
MPG Quartile 4 * Gasoline Price (most fuel efficient)	49.256** (17.083)

We find that a \$1 increase in gasoline price is associated with a *lower* negotiated price of cars in the least fuel efficient quartile by \$325 but a *higher* price of cars in the most fuel efficient quartile by \$49. Overall, the change in negotiated prices seems to be monotonically related to the fuel efficiency of the car of interest. Note that this is the equilibrium price effect: The price change is the net effect of the manufacturer price response, any potential change in consumers' willingness to pay, and the change in the dealers' reservation price for the car.

We also estimate Equation 6 separately for each segment . To do this we create segment-specific fuel efficiency quartiles. The results are in Table 6. One might expect to find the same pattern segment by segment, namely that prices decrease significantly for the lowest fuel efficiency quartile in each segment, decrease somewhat less for quartile 2, even less for quartile 3, and perhaps increase for quartile 4. This is the pattern in the results for SUVs and luxury cars. The prices of the SUVs of below median fuel efficiency fall significantly while prices for above median fuel efficiency SUVs weakly increase. Luxury cars show a price decrease of over \$1300 for the least fuel efficient luxury cars, and a price increase of over \$200 for the most fuel efficient. Such large price effects are somewhat surprising given the absence of any statistically significant market share change for luxury cars.

This pattern need not be the case, however, particularly if one keeps in mind the results of the previous subsection showing that increased gasoline prices lead to substitution between segments. For example, compact cars exhibit price increases, irrespective of fuel efficiency quartile, suggesting overall substitution into the compact segment. Conversely we find that pickup trucks exhibit price decreases, irrespective of fuel efficiency quartile, suggesting general substitution out of the segment. The remaining segments behave less predictably. Midsize cars exhibit price decreases for cars in the most and the least fuel efficient quartile. Sporty cars show no price changes, except for price increases in the second lowest fuel efficiency quartile. Finally, vans showed price increases for the most and least fuel efficient quartiles, and a price decrease in the second lowest quartile.

4.3 Trade-ins

One of the unique features of our data, among papers that have addressed this topic, is that we observe transactions for individual cars, including what car was traded in–if any–for the new car. Thus, for the 40% of transactions that involve a trade-in, we can see what a customer purchases currently compared to what that same customer purchased at some point in the past. This allows us to perform analysis that is in the spirit of a within customers analysis.[10] We do this by looking at the difference between the MPG of the new car and trade-in, and by relating that difference to fuel prices. We are also interested in how the composition of trade-ins change as a result of gasoline prices.

4.3.1 Specification and variables

For the 40% of transactions that involve trade-ins, we calculate the difference between the MPG of the new car and the MPG of the trade-in car. In this version of the paper we are restricted by our MPG data to only consider trade-ins of 1999 vintage of newer (in a subsequent version we will expand to older cars).

Our trade-in specification is as follows:

$$\text{Diff}_{irjt} = \beta_0 + \beta_1 \text{GasolinePrice}_{it} + \beta_2 \text{Demog}_{it} + \beta_3 \text{PurchaseTiming}_{jt} + \delta_k + \tau_t + \mu_{rt} + \xi_{ijkt} \quad (7)$$

Diff_{irjt} is the difference in MPG between the new car of car type j sold in transaction i in region r on date t and the car k that was traded in during that transaction. (For this specification we drop all transactions for which there was no trade-in.) The variable of primary interest is *GasolinePrice*, which is specific to the month in which the vehicle was purchased and to the ZIP code of the buyer.

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[10] We cannot do an exact within customer model because we do not observe multiple new car purchases by the same customer. We also do not know when a trade-in was purchased because a given model year is usually available for long over a year (as long as 18 months is not uncommon). Furthermore, we cannot tell if the trade-in was originally purchased new or used.

We use a set of controls similar to what we have used in the market share specification (see page 15), except that we control for car type fixed effects of the trade-in (δ_k) instead of car type fixed effects for the new car (δ_j in previous specifications). This means that the coefficient of interest β_1 measures the effect of a gasoline price increase, holding constant the car that was traded in. The variation in Diff_{irjt} thus arises from differences in the MPG of the new cars that were purchased as a result of gasoline price changes.

We are also interested in how the composition of trade-ins—their fuel efficiency in particular—changed as a result of gasoline prices. Of course a consumer cannot make a trade-in more or less fuel efficient; however, some consumers may be able to decide which of several existing cars to trade-in, and also whether to accelerate replacing a fuel-inefficient car with a new car due to rising gasoline prices. To see whether we can find evidence for these two explanations we run the following two specifications:

$$\text{Trade MPG}_{irjt} = \kappa_0 + \kappa_1 \text{GasolinePrice}_{it} + \kappa_2 \text{Demog}_{it} + \kappa_3 \text{PurchaseTiming}_{jt} + \tau_t + \mu_{rt} + \xi_{ijkt} \tag{8}$$

$$\begin{aligned} \text{Trade Age}_{irjt} = \theta_0 &+ \theta_1 (\text{GasolinePrice}_{it} \cdot \text{Trade MPG Quartile}_j) + \theta_2 \text{Demog}_{it} + \\ &\theta_3 \text{PurchaseTiming}_{jt} + \tau_t + \mu_{rt} + \xi_{ijkt} \end{aligned} \tag{9}$$

The first specification investigates whether gasoline prices change the fuel efficiency of trade-ins. It mirrors Equation 7, except for the left hand side variable. The second specification investigates whether the age of the trade-in changes with gasoline prices and thus measures whether consumers accelerate replacing their existing car with a new car. Since this decision is likely to depend on the fuel economy of the trade-in, we interact *GasolinePrice* with the fuel efficiency quartile of the trade-in.

4.3.2 Trade-in results

The gasoline price coefficient for all three trade-in specifications are as follows (see Table 7 for more details):

	Dependent Variable		
	MPG - Trade MPG	Trade MPG	Trade Age
Gasoline Price	1.02** (0.11)	-0.290** (0.059)	
Trade MPG Quartile 1 * Gasoline Price (least fuel efficient)			-1.044** (0.044)
Trade MPG Quartile 2 * Gasoline Price			-0.962** (0.044)
Trade MPG Quartile 3 * Gasoline Price			-0.976** (0.047)
Trade MPG Quartile 4 * Gasoline Price (most fuel efficient)			0.820** (0.052)

The first column reports the effect of gasoline prices on the difference between the fuel efficiency of the new car and the trade-in (Equation 7). We find that higher gasoline prices are associated with a larger difference between the fuel efficiency of the new car and the trade-in. The estimated coefficient implies that a $1 increase in the gasoline price leads customers to choose a new car whose fuel efficiency exceeds that of their trade-in car by 1.02 *more* than before the fuel price increase.[11] To put this into perspective, the interquartile range is 17.5 to 24.5 MPG, which means 1 MPG is about one-seventh of the interquartile range

The second column reports on the effect of gasoline prices on the fuel efficiency of the car that was traded in. If increased fuel prices lead customers to be more likely to trade in the least fuel efficient car in their portfolio of cars, or if it leads to customers delaying new car purchases if their existing cars are fuel efficient but accelerate new car purchases if their existing cars are fuel inefficient, then we would expect a negative fuel price coefficient. We find that a $1 increase in gasoline prices is associated with a 0.3 MPG decrease in the fuel consumption of the trade-in, which suggests that consumers are trading in cars with lower fuel efficiency when gasoline prices are higher.

The last column reports on the effect of gasoline prices on the age of the trade-in. This specification measures more directly whether consumers accelerate replacing their existing car

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[11] Notice that our coefficient of interest is not picking up changes in consumers' MPG tastes over time. For example, it could be that in this period, net of gasoline price effects, most consumers would prefer a new car that is increasingly less fuel efficient than their existing car. Such effects should be largely captured by our year dummies. Instead, the gasoline price coefficient solely captures which part of the MPG change from trade-in to new car can be explained with a variation in gasoline prices.

with a new car. We find that for trade-ins in the first 75% of the MPG distribution of trade-ins (i.e. in the three least fuel efficient quartiles), a $1 increase in gasoline prices reduces the age of the trade-in by 1 year, suggesting that consumers accelerate their car purchase. In contrast, trade-ins in the most fuel efficient quartile are 0.8 years older, suggesting that consumers hold on longer to fuel efficient cars when gasoline prices are higher.

4.3.3 Transition matrices

Another way to explore the relationship between trade-ins and new cars is to construct transition matrices showing how customers with trade-ins of differing fuel efficiencies transition into new cars. We do this by placing new cars and trade-ins into separate fuel efficiency quintiles. We then ask: conditional on the trade-in being in a given fuel efficiency quintile, in which fuel efficiency quintile is the new car that the consumer purchases? We divide the observations by whether the new car transactions occur at a time when gasoline prices are below or above median gasoline prices. The results are in Figure 12.

Figure 12: Trade-in transition matrices by gasoline prices

		... in which quintile is new car?				
		1	2	3	4	5
Conditional on	1	66.2	15.5	10.5	4.4	3.4
trade-in in	2	44.1	31.1	12.9	6.4	5.5
quintile ...	3	21.6	29.2	35.1	8.4	5.7
	4	14.3	19.9	30.9	26.0	9.0
	5	10.1	17.1	20.8	21.3	30.7

Below median gasoline prices

... in which quintile is new car?				
1	2	3	4	5
56.4	17.8	12.4	6.9	6.5
35.8	30.1	16.2	8.6	9.3
16.6	24.9	37.9	11.8	8.8
11.3	18.7	26.7	28.0	15.3
8.6	15.4	18.9	21.7	35.4

Above median gasoline prices

	1	2	3	4	5
1	-9.8	2.3	1.9	2.5	3.0
2	-8.4	-1.0	3.3	2.3	3.8
3	-5.0	-4.4	2.8	3.4	3.1
4	-3.0	-1.2	-4.1	2.0	6.3
5	-1.5	-1.7	-1.9	0.3	4.7

Percentage point difference

The numbers in the upper part of the figure represent the percentage of buyers whose trade-in is in a given fuel efficiency quintile (a row) who chose a new car of a given fuel efficiency quintile (column). For example, on the top left hand side of Figure 12, of all buyers whose trade-in was in fuel-efficiency quintile 1 (row 1, the least fuel efficient quintile of trade-ins), 66% purchased a new car that was also in fuel efficiency quintile 1 (column 1, the least fuel efficient quintile of new cars), 16% purchased a new car in fuel efficiency quintile 2 (column 2), and so on. If many consumers' preferences over vehicles (size and power in particular) are stable over time we would expect to see a lot of mass in the transition matrix on the diagonal, and in fact we do. If higher gasoline prices tend to increase the fuel efficiency of new cars consumers choose relative to the fuel efficiency of their trade-ins, we should see the mass of consumers shift to the right as we move from the "below median gasoline price panel" in Figure 12 to the "above the median gasoline price panel." This is indeed what we see for every quintile of trade-in. The third panel in the figure shows the percentage point difference between above and below median gasoline price panels. As the table shows, the distribution of consumers moves quite noticeably towards the right as gasoline prices increase.

One concern is whether these results arise due to geographic variation in gasoline prices and tastes. For example, California buyers are more likely to face above median gasoline prices than other buyers. If California buyers–irrespective of gasoline prices–are more likely to upgrade to more fuel efficient vehicles than buyers in other regions, this would explain why the mass of consumers on the right hand side of Figure 12 is shifted to the right relative to the left hand side of the figure. To see whether this is a concern, Figure 15 on page 38 repeats the analysis using data for California. The results show a similar pattern of similar size effects.

5 Extensions

So far we have focused on the effect of fuel prices in customer transactions for new cars. In this section, we turn our attention upstream, investigating the role of fuel prices on manufacturers and dealers. First, we consider how gasoline price affects dealer inventories. Second, we investigate how the MPG distribution of available and purchased cars in the U.S. has change during our sample period.

5.1 Inventories

We have shown that consumers are buying fewer fuel inefficient cars when gasoline prices rise. This raises the question of what is happening to these cars. Bresnahan and Ramey (1994) show that between 25 and 50% of the plant closures are for inventory adjustments. This allows manufacturers to reduce production of fuel inefficient cars when gasoline prices increase. However, are such adjustments fast enough relative to changes in sales? If not, we should observe that inventories of cars change with gasoline prices.

5.1.1 Specification and variables

We don't observe production data with the same detail as transactions. However, we know for every car that was sold how long the car was on the lot. This is a key inventory proxy used in the industry and is referred to as "days to turn" (DTT). The longer days to turn, the higher the inventory of the dealer relative to sales of a particular vehicle.

Our inventory specification is as follows:

$$\begin{aligned} DTT_{irjt} = \omega_0 + \omega_1(\text{Gasoline Price}_{it} \cdot \text{MPG Quartile}_j) + \omega_2 \text{Demog}_{it} + \\ \omega_3 \text{PurchaseTiming}_{jt} + \delta_j + \tau_t + \mu_{rt} + \nu_{ijt} \end{aligned} \tag{10}$$

DTT_{irjt} measures days to turn for transaction i in region r on date t for car j. As we have shown in the last section, as gasoline prices increase, some cars experience sales decreases while other experience sales increases. If sales changes affect inventory levels, we would expect that the inventory levels of the least fuel efficient cars should increase when gasoline prices are high while the inventory levels of the most fuel efficient cars should decrease as a result of a gasoline price increase. To capture this, we estimate separate coefficients for the *GasolinePrice* variable, depending on MPG quartile into which car j falls within the MPG distribution of cars available for sale in the United States.

We use the same extensive set of controls we have used in the market share specification (see page 15).

5.1.2 Inventory results

The full results from estimating the specification in Equation 10 are presented in Table 8. The coefficients of interest are as follows:

Variable	Coefficient/SE	DTT sample mean	% Change DTT
Quartile 1 * Gasoline Price (least fuel efficient)	11.19** (0.72)	62.7	18%
Quartile 2 * Gasoline Price	9.08** (0.64)	63.4	14%
Quartile 3 * Gasoline Price	-1.6** (0.53)	62.4	-3%
Quartile 4 * Gasoline Price (most fuel efficient)	-9.64** (0.5)	46.2	-21%

The estimated coefficients imply that a $1 increase in gasoline price is associated with an *increase* in days to turn for cars in the least fuel efficient quartile. These cars remain 11.2 days longer on the lot, an 18% increase from the sample mean of 62.7 days. Conversely, we find that the same gasoline price increase *reduces* by 9.6 days the time that a car in the most fuel efficient quartile remains in the lot. Since cars in this quartile remain on average 46.2 days on the lot before selling, this is a 21% decrease.

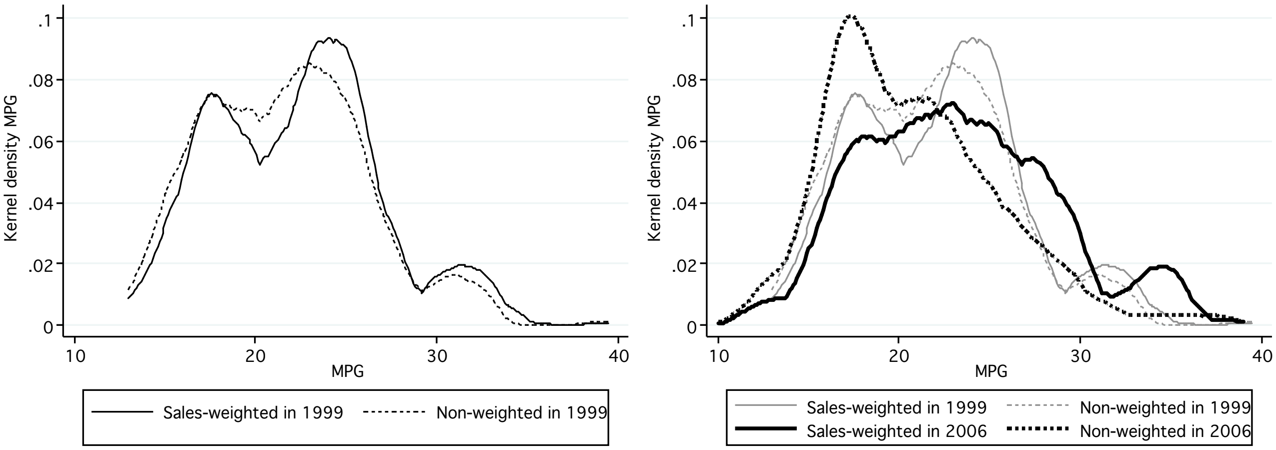
These results suggest that manufactures cannot react fast enough to changes in vehicle sales due to gasoline prices to keep dealer inventories unaffected. Instead, dealer inventories change substantially in response to gasoline price changes.

5.2 Distribution of fuel efficiency

Our final extension investigates how the fuel efficiency distribution of offered and purchased cars in the U.S. has changed during our sample period. We compare the distribution of fuel efficiency (MPG) of cars offered and purchased in 1999 with the distribution of fuel efficiency

(MPG) of cars offered and purchased in 2006. The distributions (a kernel density plot) are shown in Figure 13. The dashed line in the left panel of the figure shows the distribution of MPG of car types that were *offered for sale* in the U.S. in 1999, where a "car type" is the interaction of make, model, model year, body type, transmission, displacement, doors, cylinders, and trim level. The figure refers to the distribution as "non-weighted" to describe that each car type has equal weight in the distribution regardless of sales volume. The solid line in the left panel of the figure shows the distribution of MPG of cars that were *purchased* in the U.S. in 1999, meaning that car types enter the MPG distribution weighted by their sales in the transaction data. Notice that the two distributions overlap nearly perfectly: During 1999, the probability with which U.S. consumers purchased a car type of a particular fuel efficiency was proportional to the number of available car types of that fuel efficiency.

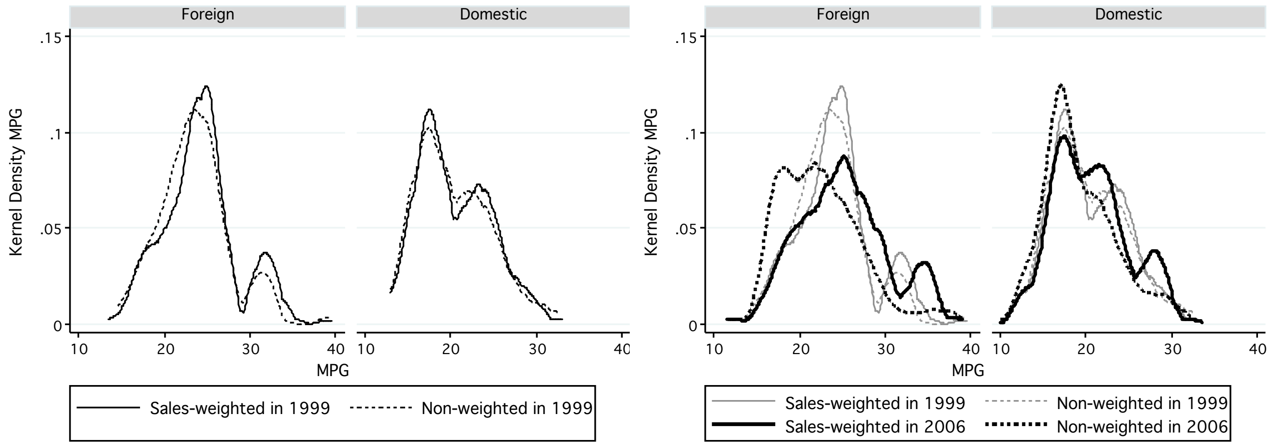
Figure 13: MPG distribution of available ("non-weighted") and purchased ("sales-weighted") cars in 1999 and 2006



What consumers purchased and what manufacturers offered changed substantially from 1999 to 2006. The right panel of Figure 13 adds the 2006 distributions to the 1999 distributions. As can be seen by comparing the thin (1999) solid with the thick (2006) solid line, consumers purchases shifted towards *more* fuel efficient cars. Surprisingly, during this time car manufacturer offerings shifted to *less* fuel efficient vehicles. This can be seen by comparing the thin (1999) dashed with the thick (2006) dashed line.

Given that that U.S. auto manufacturers are frequently criticized for relying too much on fuel inefficient cars, one might think that U.S. auto manufacturers are responsible for the difference in the distributions between offered and purchased cars in 2006. To investigate whether this is the case, Figure 14 splits up the fuel efficiency distributions by domestic and foreign car manufacturers.

Figure 14: Foreign vs. domestic MPG distribution of available ("non-weighted") and purchased ("sales-weighted") cars in 1999 and 2006



The left panel of the figure compares the fuel efficiency distributions for foreign and domestic cars that were offered for sale (dashed line) and purchased (solid lines) in the U.S. in 1999. As the figure shows, for both domestic *and* foreign manufacturers, the probability with which U.S. consumers purchased a car of a particular fuel efficiency during 1999 was proportional to the number of available cars of that fuel efficiency. Surprisingly, the divergence of the "offered" vs. "purchased" distributions in 2006 is mostly driven by foreign, not domestic, manufacturers. As can be seen in the right panel of Figure 14, the offering of domestic manufactures (in terms of fuel efficiency) changed little between 1999 and 2006. Furthermore, for domestic manufacturers, the distribution of customer purchases closely follows the distribution of offered cars in 2006, just as it does in 1999. In contrast, buyers of foreign cars purchased more fuel *efficient* cars in 2006 than in 1999 while foreign manufacturers offered many more fuel *inefficient* vehicles in 2006 than they had offered in 1999.

One explanation for this pattern is that foreign manufacturers had more room to expand into more fuel inefficient vehicles than domestic manufacturers. This is because corporate average fuel economy (CAFE) standards have long been binding for domestic manufactures but not for Asian manufacturers (Jacobsen 2008). As a result, Toyota, Nissan, Honda, and others have been able to add large SUVs and pickup trucks to their model offerings without violating CAFE standards. Although the distributions of offered vs. purchased vehicles for foreign manufacturers diverge in 2006, this does not imply that the offerings of car manufacturers were not profit maximizing. Large, fuel inefficient vehicles often carry higher profit margins for manufacturers, which may make them worth adding to a product line, even if they do not attract sales in proportion to the offerings.

6 Concluding remarks

In this paper we have investigated the effect of gasoline prices on a variety of aspects of automobile purchasing. We found statistically significant effects of fuel prices on market shares, vehicle prices, trade-in utilization, and inventories. The results indicate that increasing gasoline prices have an effect throughout the new car industry, and that customers respond to increase gasoline prices by buying more fuel efficient cars (in aggregate and relative to their own past purchases), by trading in more fuel inefficient cars, and by being willing to pay a premium for fuel efficient new cars.

The magnitude of the effects are economically significant, both for changing the composition of vehicles on the road and certainly for affecting the profitability of auto manufacturers. One question that our introduction implicitly raises, but which we have not yet answered is whether these effects are significant enough to alter the effects of climate change. In future drafts of this paper, we intend to use our results to relate hypothetical gasoline taxes or carbon taxes to the greenhouse gas emissions effect of the resulting change in composition of the U.S. vehicle fleet.

We will also extend our data into 2008, allowing us to investigate the effect of the increase in gasoline prices from around \$3 in 2006 to near \$4 in 2008. News accounts and the automotive trade press seem to suggest that the effects of the gasoline price increase in this range were larger than the effects of the increases that preceded it.

Finally, we note that there are many avenues through which gasoline prices would affect greenhouse gas emissions, only one of which–the short run effects on car purchasing–are covered in this paper. One other short run effect, which this paper cannot capture, is whether drivers change their driving behavior (consolidating trips, carpooling, using more public transportation) in response to gasoline prices. There are also important long-run effects which this paper does not cover. An important one is auto manufacturers' decisions about the portfolio of cars to offer. Designing a new car platform is typically a 5-10 year endeavor, so the automobile design effects of the gasoline price increases we investigate here will not be seen for some time. Another long run effect that we do not investigate here is the development of alternative fuels (or the greater availability of existing alternative fuels), or the commercialization of new automobile technologies, such as electric vehicles or plug-in hybrids. Finally, the longest run effects of sufficiently large increases in fuel prices might be redesign of towns and cities, increased telecommuting, or other sorts of infrastructure innovations. This is far beyond what this paper can inform.

Even though this paper cannot cover all the aspects of the relationship between gasoline prices and the climate change effect of transportation, we believe that it yields valuable insights about what the short run effects might be, and that that is an important piece of the larger overall question.

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Figures

Figure 15: California trade-in transition matrices by gasoline prices

		... in which quintile is new car?				
		1	2	3	4	5
Conditional on	1	64.1	15.8	11.6	5.6	2.9
trade-in in	2	48.3	27.1	12.4	6.8	5.5
quintile ...	3	26.0	31.2	29.0	8.2	5.6
	4	18.3	21.5	29.3	23.3	7.7
	5	13.3	18.0	24.5	23.1	21.2

Below median gasoline prices

	... in which quintile is new car?				
	1	2	3	4	5
1	57.0	18.1	12.1	6.5	6.3
2	39.0	29.4	15.6	7.5	8.5
3	20.2	25.9	35.0	10.5	8.4
4	13.6	19.3	27.9	25.2	14.1
5	10.6	15.9	21.1	21.5	31.0

Above median gasoline prices

	1	2	3	4	5
1	-7.1	2.4	0.5	0.8	3.4
2	-9.3	2.3	3.2	0.8	3.0
3	-5.8	-5.3	6.0	2.3	2.8
4	-4.7	-2.2	-1.4	1.8	6.5
5	-2.7	-2.1	-3.4	-1.6	9.8

Percentage point difference

Tables

Table 1: Examples of cars in segments and subsegments

Segment	Av. MPG	Subsegment	Av. MPG	Example
Compact Car	29.5	Entry Compact	30.9	Hyundai Accent, Toyota Yaris
		Premium Compact	29.0	Honda Civic, Ford Focus
Midsize Car	24.9	Lower Midsize Car	26.0	Pontiac G6, VW Jetta
		Upper Midsize Car	24.4	Honda Accord, Ford Fusion, Nissan Altima
Luxury Car	21.8	Near Luxury Car	23.1	BMW 3-Series, Volvo V70
		Traditional Luxury Car	21.5	Cadillac Deville, Lincoln Town Car
		International Luxury Car	20.8	BMW 5-Series, Mercedes S-Class
Sporty Car	23.3	Entry Sporty Car	29.7	VW Golf GTI, Hyundai Tiburon
		Middle Sporty Car	24.3	Audi A3, Ford Mustang
		Premium Sporty Car	21.9	Chevrolet Corvette, Porsche 911
SUV	18.7	Mini SUV	21.7	Honda CRV, Ford Escape
		Compact SUV	18.3	Toyota 4Runner, Dodge Durango
		Fullsize SUV	15.4	GMC Yukon, Toyota Sequoia
		Luxury SUV	17.1	Acura MDX, Cadillac Escalade
Pickup	17.5	Compact Pickup	18.8	Ford Ranger, Dodge Dakota
		Fullsize Pickup	16.2	Ford F150, Chevrolet Silverado 1500
Van	19.3	Compact Van	20.7	Honda Odyssey, Dodge Grand Caravan
		Fullsize Van	16.0	Dodge Ram Van 2500, Ford Club Waron E-150

Table 2: Sales results, fuel efficiency quartiles[†]

	MPG Quartile 1	MPG Quartile 2	MPG Quartile 3	MPG Quartile 4
GasolinePrice	-.024**	-.019**	-.011*	.057**
	(.0063)	(.0058)	(.0041)	(.01)
PctLessHighSchool	.019	.03*	-.0037	-.049*
	(.015)	(.013)	(.012)	(.019)
PctCollege	-.04*	.016	.033**	.0068
	(.015)	(.013)	(.009)	(.02)
Income	9.2e-08	2.9e-07**	3.2e-07**	-4.9e-07**
	(1.0e-07)	(9.9e-08)	(9.3e-08)	(1.3e-07)
MedianHHSize	.014**	.0072**	-.0044	-.012
	(.0034)	(.0022)	(.0048)	(.0077)
MedianHouseValue	4.4e-08	3.2e-08	6.3e-08**	-1.3e-07*
	(3.4e-08)	(2.1e-08)	(1.1e-08)	(5.6e-08)
VehiclePerHH	.044**	.0084	-.034**	-.04*
	(.0091)	(.0042)	(.0055)	(.016)
TravelTime	-.000051	-.00016	-.00049**	.00049
	(.00018)	(.00013)	(.00016)	(.00026)
Year 2000	-.0097*	-.014*	.0054	.029**
	(.004)	(.006)	(.0059)	(.0064)
Year 2001	-.026**	-.024**	-.014	.087**
	(.0045)	(.008)	(.008)	(.0082)
Year 2002	-.02**	-.027**	-.035**	.089**
	(.0057)	(.0079)	(.0085)	(.007)
Year 2003	.0031	-.046**	-.026**	.079**
	(.0058)	(.01)	(.0092)	(.0062)
Year 2004	.0054	-.033*	.0056	.05**
	(.007)	(.012)	(.01)	(.0089)
Year 2005	.0095	-.03*	-.019	.062**
	(.0089)	(.015)	(.012)	(.013)
Year 2006	-.022*	-.021	-.024	.092**
	(.01)	(.016)	(.013)	(.017)
Weekend	-.015**	.0013	-.00046	.024**
	(.0014)	(.0018)	(.0013)	(.003)
EndOfMonth	.0043**	-.00098	.0024**	-.0064**
	(.00096)	(.00099)	(.00086)	(.0011)
EndOfYear	-.0058**	.0062	-.0066*	.011*
	(.0019)	(.0038)	(.0028)	(.0044)
ModelMonths	.0043**	.0039**	-.0002	-.0066**
	(.00033)	(.00028)	(.00023)	(.00034)
Constant	.32**	.2**	.076*	.15**
	(.034)	(.049)	(.034)	(.042)
Observations	1368312	1368312	1368312	1311798
R-squared	0.0207	0.0068	0.0108	0.0314

* significant at 5%; ** significant at 1%; + significant at 10% level. SEs in parentheses.
Not reported: Region fixed effects, month of year fixed effects, and their interaction. We also don't report house ownership, occupation, english proficiency, and race of buyers.

Table 3: Sales results, segments[†]

	Compact	Midsize	Luxury	Sporty	SUV	Pickup	Van
GasolinePrice	.019**	.022**	.005	.00089	-.027**	-.013**	-.0054**
	(.005)	(.0044)	(.0039)	(.0014)	(.0096)	(.0043)	(.0015)
PctLessHighSchool	-.032	-.015	.052**	-.024**	-.011	.043*	-.013
	(.016)	(.016)	(.012)	(.0041)	(.015)	(.018)	(.0071)
PctCollege	-.00079	-.014	.064**	.0017	.095**	-.14**	.014*
	(.012)	(.018)	(.011)	(.0029)	(.015)	(.023)	(.0068)
Income	-1.3e-07	-3.7e-07**	7.4e-07**	4.7e-08*	3.6e-07*	-5.8e-07**	-8.0e-08*
	(1.1e-07)	(8.3e-08)	(1.0e-07)	(2.1e-08)	(1.4e-07)	(1.3e-07)	(3.6e-08)
MedianHHSize	-.002	-.0019	-.031**	.00032	.013*	.0086*	.017**
	(.0047)	(.0045)	(.0024)	(.00099)	(.005)	(.0039)	(.0034)
MedianHouseValue	-7.1e-08	-9.5e-08**	2.1e-07**	2.5e-10	5.0e-08	-6.5e-08**	-2.8e-08**
	(3.9e-08)	(1.9e-08)	(2.9e-08)	(4.1e-09)	(3.5e-08)	(1.5e-08)	(8.2e-09)
VehiclePerHH	-.017	-.041**	-.022**	.0028	.0035	.086**	-.0051
	(.012)	(.0077)	(.0052)	(.0021)	(.0083)	(.0087)	(.0032)
TravelTime	.00031	.00026	-.00091**	.000076	-.00011	.00065**	-.00015
	(.00028)	(.00022)	(.0002)	(.000081)	(.0002)	(.00022)	(.000073)
Year 2000	.013**	-.016**	.0017	-.00084	.00034	.0036	-.0025
	(.0033)	(.0056)	(.0029)	(.001)	(.0056)	(.0039)	(.0019)
Year 2001	.015**	-.024**	.0066**	-.0014	.02**	.0029	-.017**
	(.0037)	(.0062)	(.0024)	(.0014)	(.0067)	(.0039)	(.0025)
Year 2002	.018**	-.032**	.012**	-.007**	.035**	-.0019	-.021**
	(.0035)	(.0077)	(.0024)	(.0017)	(.0074)	(.004)	(.0028)
Year 2003	.012**	-.047**	.011*	-.014**	.062**	.0059	-.025**
	(.004)	(.0085)	(.0044)	(.002)	(.0094)	(.0041)	(.0034)
Year 2004	.0067	-.061**	.013*	-.013**	.07**	.014*	-.022**
	(.0053)	(.0096)	(.0058)	(.0021)	(.01)	(.0066)	(.0035)
Year 2005	.0032	-.067**	.01	-.0083**	.073**	.018	-.02**
	(.0073)	(.011)	(.0074)	(.0024)	(.013)	(.0087)	(.0037)
Year 2006	.015	-.078**	.011	-.006	.082**	.0034	-.018**
	(.0085)	(.012)	(.009)	(.003)	(.016)	(.0099)	(.0052)
Weekend	.014**	.014**	-.012**	-.00066	.0085**	-.017**	-.0036**
	(.0016)	(.0022)	(.0024)	(.0005)	(.002)	(.0021)	(.00097)
EndOfMonth	-.0077**	4.9e-06	.0081**	-.0039**	.0014	-.00034	.002*
	(.00086)	(.00097)	(.0011)	(.00042)	(.00087)	(.00077)	(.00075)
EndOfYear	.00033	.014**	-.012**	-.0012	.00071	-.0031	.002
	(.003)	(.004)	(.0032)	(.0015)	(.0035)	(.0022)	(.0024)
ModelMonths	-.00097**	-.002**	-.0025**	-.00014	.0035**	.0012**	.00059**
	(.00029)	(.0002)	(.00022)	(.000095)	(.00024)	(.00034)	(.00015)
Constant	.1*	.099	.093**	.0057	-.012	.69**	-.015
	(.049)	(.064)	(.027)	(.017)	(.054)	(.073)	(.028)
Observations	1368312	1368312	1368312	1368312	1368312	1368312	1368312
R-squared	0.0176	0.0155	0.0496	0.0034	0.0152	0.0654	0.0062

* significant at 5%; ** significant at 1%; + significant at 10% level. SEs in parentheses.

Not reported: Region fixed effects, month of year fixed effects, and their interaction. We also don't report house ownership, occupation, english proficiency, and race of buyers.

Table 4: Sales results, subsegments[†]

	Entry Compacts	Prem Compacts	Lower Mid	Upper Mid
Gasoline Price	0.005**	0.014**	0.005*	0.015**
	(0.001)	(0.005)	(0.002)	(0.004)
Obs.	1368312	1368312	1368312	1368312
Adj. R2	0.004	0.015	0.008	0.012

	Near Luxury	Trad Luxury	Intl Luxury	
Gasoline Price	0.003	0.000	0.003	
	(0.002)	(0.001)	(0.002)	
Obs.	1368312	1368312	1368312	
Adj. R2	0.024	0.005	0.036	

	Entry Sporty	Mid Sporty	Prem Sporty	
Gasoline Price	0.000	-0.001	0.001	
	(0.000)	(0.001)	(0.001)	
Obs.	1368312	1368312	1368312	
Adj. R2	0.001	0.004	0.004	

	Mini SUV	Comp.SUV	Fullsize SUV	Luxury SUV
Gasoline Price	-0.003	-0.009+	-0.012**	-0.003
	(0.003)	(0.005)	(0.002)	(0.003)
Obs.	1368312	1368312	1368312	1368312
Adj. R2	0.006	0.012	0.015	0.031

	Comp Pickup	Fullsize Pickup	Mini Van	Fullsize Van
Gasoline Price	0.006*	-0.019**	-0.006**	0.000
	(0.003)	(0.003)	(0.002)	(0.000)
Obs.	1368312	1368312	1368312	1368312
Adj. R2	0.013	0.058	0.007	0.002

[*] significant at 5%; ** significant at 1%; + significant at 10% level. SEs in parentheses.

Table 5: Price results, fuel efficiency quartiles†

Variable	Coefficient/SE
MPG Quartile 1 * Gasoline Price (least fuel efficient)	-324.976** (24.665)
MPG Quartile 2 * Gasoline Price	-183.135** (21.787)
MPG Quartile 3 * Gasoline Price	-20.416 (18.222)
MPG Quartile 4 * Gasoline Price (most fuel efficient)	49.256** (17.083)
Observations	1368312
R-squared	0.957

[*] significant at 5%; ** significant at 1%; + significant at 10% level. SEs in parentheses.

Not reported: Region fixed effects, month of year fixed effects, and their interaction; year fixed effects, WeekEnd, EndOfMonth, EndOfYear, ModelMonths. We also don't report education, income, median household size, median house value, vehicles per household, average travel time to work, house ownership, occupation, english proficiency, and race of buyers.

Table 6: Price results, fuel efficiency quartiles by segment†

	Compacts	Midsize	Luxury	Sporty Cars	SUVs	Pickups	Vans
Q-tile 1 * Gas. Price (least fuel efficient)	132.664** (42.635)	-182.525** (49.987)	-1320.810** (132.435)	148.286 (116.356)	-426.192** (44.312)	-576.958** (67.350)	434.963* (193.420)
Q-tile 2 * Gas. Price	51.175 (42.005)	87.916* (41.017)	-60.589 (80.421)	488.016** (107.370)	-421.146** (43.675)	-301.649** (57.936)	-418.532** (102.883)
Q-tile 3 * Gas. Price	55.262+ (29.154)	27.506 (31.711)	-41.596 (75.277)	-173.880 (126.281)	73.971+ (39.445)	-364.537** (49.182)	-58.941 (68.948)
Q-tile 4 * Gas. Price (most fuel efficient)	263.533** (24.766)	-136.283** (31.729)	217.780** (66.098)	124.036 (108.772)	16.996 (38.671)	-103.149* (46.118)	240.615** (65.649)
R2	0.85	0.82	0.97	0.97	0.93	0.89	0.79
Obs.	214178	264500	120809	55837	363116	238830	94747

[*] significant at 5%; ** significant at 1%; + significant at 10% level. SEs in parentheses.

Not reported: Region fixed effects, month of year fixed effects, and their interaction; year fixed effects, WeekEnd, EndOfMonth, EndOfYear, ModelMonths. We also don't report education, income, median household size, median house value, vehicles per household, average travel time to work, house ownership, occupation, english proficiency, and race of buyers.

Table 7: Trade-in results[†]

	MPG – Trade MPG	Trade MPG	Trade Age
GasolinePrice	1** (.11)	-.29** (.059)	
GasolinePrice*MGP Quart 1			-1** (.044)
GasolinePrice*MGP Quart 2			-.96** (.044)
GasolinePrice*MGP Quart 3			-.98** (.047)
GasolinePrice*MGP Quart 4			.82** (.052)
PctLessHighSchool	-.12 (.19)	-.65+ (.37)	.26 (.16)
PctCollege	.22 (.19)	.14 (.28)	.69** (.11)
Income	-1.4e-06 (1.2e-06)	-1.3e-06 (2.3e-06)	-4.4e-07 (8.5e-07)
MedianHHSize	-.35** (.057)	-.21** (.066)	-.12** (.026)
MedianHouseValue	-1.9e-07 (3.7e-07)	-1.9e-06** (5.8e-07)	4.3e-07* (1.8e-07)
VehiclePerHH	-.21* (.095)	-.98** (.13)	-.18** (.056)
TravelTime	.0037 (.0037)	.01** (.0028)	-.0099** (.0019)
Year 2000	.051 (.17)	.16 (.17)	.018 (.031)
Year 2001	.18 (.17)	.34 (.21)	.092* (.04)
Year 2002	.45* (.19)	.33 (.23)	.26** (.046)
Year 2003	.47* (.19)	.32 (.24)	.28** (.045)
Year 2004	.72** (.2)	.28 (.25)	.31** (.056)
Year 2005	1** (.2)	.48+ (.28)	.59** (.073)
Year 2006	1.1** (.22)	.82* (.31)	.77** (.086)
Weekend	.022 (.036)	.25** (.029)	.13** (.013)
EndOfMonth	-.068** (.019)	-.035+ (.019)	-.000061 (.01)
EndOfYear	.1 (.086)	-.013 (.056)	.13** (.037)
ModelMonths	-.094** (.0042)	-.021** (.003)	.016** (.0011)
Constant	-2.7** (.88)	21** (.71)	4.4** (.59)
Observations	270025	279741	552701
R-squared	0.282	0.043	0.223

[*] significant at 5%; ** significant at 1%; + significant at 10% level. SEs in parentheses.

Not reported: Region fixed effects, month of year fixed effects, and their interaction. We also don't report house ownership, occupation, english proficiency, and race of buyers.

Table 8: Inventory results, fuel efficiency quartiles†

	Days to Turn
GasolinePrice*MGP Quart 1	12** (.72)
GasolinePrice*MGP Quart 2	9.4** (.64)
GasolinePrice*MGP Quart 3	-1.2* (.53)
GasolinePrice*MGP Quart 4	-10** (.52)
MGP Quart 1	-79 (79)
MGP Quart 2	-26 (48)
MGP Quart 3	-9.3 (45)
MGP Quart 4	-542 (1.4e+10)
PctLessHighSchool	.24 (1.2)
PctCollege	-1.6+ (.96)
Income	-.000022** (6.0e-06)
MedianHHSize	.75** (.21)
MedianHouseValue	-3.4e-06** (8.3e-07)
VehiclePerHH	.31 (.31)
TravelTime	.0031 (.01)
Year 2000	68** (2)
Year 2001	139** (4)
Year 2002	200** (5.9)
Year 2003	269** (7.9)
Year 2004	340** (9.8)
Year 2005	406** (12)
Year 2006	473** (14)
Weekend	2.8** (.13)
EndOfMonth	1.6** (.15)
EndOfYear	3.3** (.45)
ModelMonths	2.4** (.16)
Constant	-77 (4.2e+09)
Observations	1261722
R-squared	0.311

[*] significant at 5%; ** significant at 1%; + significant at 10% level. SEs in parentheses.

Not reported: Region fixed effects, month of year fixed effects, and their interaction. We also don't report house ownership, occupation, english proficiency, and race of buyers.