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The Price of Gasoline and the Demand for Fuel Economy: Evidence from Monthly New Vehicles Sales Data

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THE PRICE OF GASOLINE AND THE DEMAND FOR FUEL ECONOMY: EVIDENCE FROM MONTHLY NEW VEHICLES SALES DATA*

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ABSTRACT

This paper uses a unique data set of monthly new vehicle sales by detailed model from 1978-2007, and implements a new identification strategy to estimate the effect of the price of gasoline on consumer demand for fuel economy. We control for unobserved vehicle and consumer characteristics by using within model-year changes in the price of gasoline and vehicle sales. We find a significant demand response, as nearly half of the decline in market share of U.S. manufacturers from 2002-2007 was due to the increase in the price of gasoline. On the other hand, an increase in the gasoline tax would only modestly affect average fuel economy.

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1 INTRODUCTION

The rapid rise in the price of gasoline from just over $1 per gallon at the beginning of 2002 to over $4 per gallon by mid 2008 has renewed interest in the relationship between the price of gasoline and the demand for fuel economy in the U.S. market. Recent research on oil prices and economic activity suggests that because of improved energy efficiency, the U.S. economy as a whole is currently less sensitive to oil prices than it was prior to the 1970s oil shocks (Hooker, 1996 and Linn, 2008). In contrast, the accelerating decline of the Detroit carmakers' market share between 2005 and 2008 suggests that vehicle producers may remain quite sensitive to oil and gasoline prices.

Many industry analysts and the popular press have noted the large decrease in sales for U.S. automakers and large SUVs between 2002 and 2007, and have widely attributed some of the changes to the coinciding increase in the price of gasoline. Figure 1 depicts these trends, showing a 20 percent decrease in the market share of U.S. firms between 2002 and 2007, which represents several billion dollars per year in lost profits.[1] The figure also suggests that some of the decrease in sales by U.S. firms can be attributed to changes in the SUV segment of the market. At the beginning of this time period, U.S. firms accounted for 80 percent of sales of large SUVs (with a mean fuel economy of 16.6 miles per gallon, MPG), but only 37 percent of sales of smaller SUVs (commonly called crossover utility vehicles, with a mean fuel economy of 22.2 MPG). As the retail price of gasoline nearly doubled, the market share of small SUVs increased while the market share of large SUVs decreased. Although the contemporaneous correlations between the price of gasoline and market shares are suggestive, it needs to be recalled that fuel costs are only

[1] The market share of U.S. automakers has been declining since the mid 1950s. After stabilizing for most of the 1980s and the early 1990s, it started declining again in 1997 (Klier, 2009).

a fraction of the total cost of any vehicle, and that many other factors could explain these trends. In fact, despite the attention given to the price of gasoline by the press, analysis of the extent to which increases in the price of gasoline adversely affect U.S. automakers has so far been limited.

The effect of the price of gasoline on new vehicle demand is also central to the ongoing policy debate over reducing gasoline consumption, which has emanated from concerns about global warming and reducing oil imports.[2] In 2007, Congress passed legislation that increased the corporate average fuel economy (CAFE) standard by about 40 percent to 35 MPG, to be effective by model-year 2020. During the Congressional debate over the bill, several members of Congress advocated increasing the gasoline tax or introducing a carbon tax as alternative means of reducing gasoline consumption.[3] A comparison of the welfare effects of imposing a stricter CAFE standard and raising the gasoline tax (see Parry and Small, 2005, for the optimal gasoline tax) depends partly on the effect of the price of gasoline on the demand for fuel economy (Austin and Dinan, 2005).

Whether the price of gasoline influences new vehicle demand in an economically significant fashion remains an open question. Most previous studies analyze how the price of gasoline affects the average fuel economy of new vehicles sold, but do not provide insight into the causes of the patterns depicted in Figure 1. Furthermore, as discussed in more detail below, earlier studies do not control for both unobserved consumer and vehicle characteristics. Finally, reported estimates have varied widely across studies.

[2] See, for example, hearings at the House Energy and Commerce committee on March 14, 2007.
[3] During the summer of 2007, Congressman Dingell (MI) proposed a tax increase of 50 cents per gallon (Timiraos, 2007). During the spring of 2009 the Obama Administration moved forward the time by which the tighter fuel economy requirements must be met from model-year 2020 to model-year 2016. Greenhouse gas regulation has been added to the determination of the standard, which raises the fuel economy requirement to 35.5 MPG (Foster and Klier, 2009).

In this paper, we estimate the effect of the price of gasoline on the demand for fuel economy. We use a unique data set of monthly sales by vehicle model that spans 30 years. The data are disaggregated and of high-frequency, allowing for a simple and transparent empirical strategy that controls for unobserved consumer and vehicle characteristics. We find that the price of gasoline significantly affects the new vehicles market. Specifically, the increase in the price of gasoline from 2002-2007 explains nearly half of the decrease in the market share of U.S. firms. Furthermore, according to our estimates, a one dollar increase in the price of gasoline would modestly increase the average fuel economy of vehicles sold, by 0.5-1 MPG.

We now discuss our empirical strategy and the relationship of the paper to the previous literature in more detail. Past research has generally not accounted for the potential correlation between the price of gasoline and unobserved consumer and vehicle characteristics. Many studies rely primarily on cross-sectional variation in the price of gasoline (e.g., Goldberg, 1998, West, 2004 and Bento *et al*., 2006), and thus depend on the questionable assumption that the price is uncorrelated with unobserved consumer preferences (Chouinard and Perloff, 2007); for example, it is assumed that environmentalists are no more likely to live in states with high gasoline taxes.[4] The failure to account for unobservables is particularly problematic because the direction of the resulting bias cannot be determined from economic theory; unobserved vehicle and consumer characteristics may be positively or negatively correlated with the price of gasoline. An additional limitation of the cross-sectional analysis is that it yields an estimate of the relationship between the price of gasoline and consumer demand only for a particular point in time. Recent estimates of the elasticity of gasoline consumption with respect to the price of

[4] An earlier empirical literature estimated the effect of the price of gasoline on new vehicle demand in the 1970s (see Tardiff, 1980, for a summary). These studies have similar limitations to the more recent ones, however. For example, Boyd and Mellman (1980) find a large effect on demand using cross-sectional variation in vehicle characteristics and prices, but the study does not control for unobserved characteristics.

gasoline (e.g., Hughes *et al*., 2008) suggest that it has decreased in magnitude since the 1970s. However, it is not known whether the effect of the price of gasoline on new vehicle demand has changed as well.

Furthermore, studies that employ time series methods (e.g., Small and Van Dender, 2007) only partially address these issues as they use market-level fuel economy measures and therefore do not control for unobserved characteristics at the vehicle level, such as weight and power, which are highly correlated with fuel economy. Finally, many earlier studies analyze consumer choices only among broad vehicle classes, such as small and large cars. Their results cannot be used to assess the effect of the price of gasoline on market shares of specific market segments, such as SUVs.

This paper makes several advances beyond the existing literature. First, we use a unique data set and empirical strategy. The data include monthly national dealer sales by detailed vehicle model from 1978-2007. As Berry, Levinsohn and Pakes (1995) argue, when using market-level data it is necessary to account for the potential correlation between vehicle prices, sales and unobserved vehicle and consumer characteristics. The monthly frequency of the sales data allows for a simple linear estimating equation that controls for these unobserved variables. Our empirical strategy derives from the details of automobile production, specifically the fact that unobserved vehicle characteristics do not vary over the model-year, and that consumer tastes are likely to be slow-moving and uncorrelated with monthly variation of the price of gasoline. The empirical specification exploits within model-year changes in the monthly gasoline price and vehicle sales, while controlling for unobserved characteristics.

The second contribution of this paper is that the sample period and unit of analysis allow us to investigate a number of questions about the price of gasoline and consumer demand that have not been the focus of previous work. Access to data at the vehicle model level allows us to investigate the causes of recent market trends shown in Figure 1. In addition, we use a 30-year panel to consider whether the relationship between the price of gasoline and new vehicle demand has changed over time. By comparison, Busse *et al*. (2005, 2009) use a similar identification strategy but analyze a much shorter time frame.

The main results are reported in Section 5. We find that the increase in the price of gasoline between 2002 and 2007 explains nearly half of the decrease in market share of large SUVs but little of the increase in market share of small SUVs. Furthermore, the price increase explains nearly half of the decrease in the market share of U.S. manufacturers. Thus, the results indicate that the price of gasoline has a significant effect on the new vehicles market, but we find this relationship to be smaller in magnitude than is often suggested. We estimate the elasticity of average new vehicle fuel economy with respect to the price of gasoline to be 0.12, about half the elasticity reported in Austin and Dinan (2005). Our estimate implies that a one dollar increase in the price of gasoline raises average fuel economy by 0.5-1 MPG.

A caveat should be noted regarding these results. Like much of the previous literature on the price of gasoline and new vehicle demand, our estimates represent a short run relationship. It is possible that the long run response is greater, for example, if firms reorganize production at assembly plants across model-years in response to a permanent price change. Because our data and empirical strategy do not allow us to investigate this possibility, we treat the estimates as a lower bound to the response of vehicle demand to the price of gasoline. That is, our results quantify a short run demand response, which previously has not been demonstrated clearly.

2 Estimating the Effect of the Price of Gasoline on New Vehicle Demand

2.1 Empirical Framework

This section describes the empirical strategy for estimating the effect of the price of gasoline on the demand for fuel economy. Motivated by the two questions discussed in the introduction, the causes of recent changes in market shares and the effect of the gasoline tax on average fuel economy, we are primarily interested in estimating the equilibrium effect of the price of gasoline on market shares of new vehicle models.

We begin with the following linear approximation to the reduced form relationship between vehicle characteristics, consumer characteristics and sales:[5]

$$\ln q_{jt} = \alpha f_{jt} + X_{jt}\beta + \xi_{jt} + \nu_{jt}, \qquad (1)$$

where q_{jt} is the sales of vehicle model j at time t, f_{jt} is expected fuel costs, X_{jt} is a vector of other observed model characteristics, ξ_{jt} is a scalar representing the total effect of unobserved characteristics on sales, ν_{jt} is a scalar that represents the total effect of consumer characteristics on sales, and α and β are coefficients.

Expected fuel costs depend on the expected gasoline price over the life of the vehicle, expected miles traveled and the fuel economy of the vehicle. Observed characteristics in X_{jt} include variables such as weight, length and horsepower. Unobserved characteristics include all other aspects of the vehicle, including physical features (e.g., the presence or absence of a sunroof), as well as intangibles (e.g., handling). The consumer characteristics variable, ν_{jt},

[5] Equation (1) could be derived from a discrete choice model with the appropriate assumptions on the error term and vehicle prices (Berry, 1994). We begin with equation (1) rather than the underlying utility model because we are only interested in the effect of the price of gasoline on equilibrium sales and not on welfare effects.

accounts for the effect of heterogeneous consumer preferences on sales, for example, if wealthy consumers are more likely to purchase certain vehicle models than other consumers.[6]

2.2 Model Specification and Identification

The existence of unobserved vehicle and consumer characteristics presents major challenges to estimating equation (1). Regressing sales on fuel costs would yield biased estimates if expected fuel costs are correlated either with unobserved vehicle or consumer characteristics. Both situations are particularly likely to occur. Vehicles with high fuel economy have low fuel costs, but are also likely to have less cabin and trunk space, both of which are unobserved. The variable ν_{jt} depends on the distribution of characteristics of consumers who purchase a vehicle in time period t. The variable may be correlated with fuel costs, for example, if environmentalists tend to live in regions with a high price of gasoline. Previous work largely avoids these issues by assuming either that fuel costs are uncorrelated with other vehicle characteristics (e.g., BLP) or that the price of gasoline is uncorrelated with consumer characteristics across geographic markets (e.g., West, 2004).

We next discuss how we account for unobserved vehicle and consumer characteristics. For most vehicle production lines, the model year begins in mid-August after a brief, one- or two-week, shutdown period. During that shutdown, which separates vehicle model-years, the manufacturer may change the vehicle's characteristics such as its engine size. In practice, changes across model-years range from very minor to a complete overhaul. Once production begins, however, the features of a vehicle are constant over the model-year; a 2005 Honda Civic purchased in September of 2004 is physically the same as a 2005 Civic purchased in May of

[6] Consumer heterogeneity could also cause the coefficients α and β to vary over time and across models. Section 5.1 addresses this possibility.

2005. On the other hand, expected fuel costs depend on the expected price of gasoline, miles traveled as well as the fuel economy of the vehicle. Changes in the expected gasoline price cause expected fuel costs to vary. We therefore define a model-year specific intercept: $\phi_{jy} \equiv X_{jt}\beta + \xi_{jt} + \overline{v}_{ij}$. The intercept absorbs both observed and unobserved characteristics of the vehicle other than expected fuel costs. It also includes the mean consumer characteristics over the model-year.

Substituting ϕ_{jy} into equation (1) yields:

$$\ln q_{jt} = \alpha f_{jt} + \phi_{jy} + \varepsilon_{jt}, \quad (2)$$

where ε_{jt} is a residual that includes the effect of deviations from the mean in consumer characteristics.

We now turn to unobserved consumer characteristics. Specifically, consider the distribution of the characteristics of consumers who enter the market, i.e., who purchase a vehicle at time t. For a given month, we consider two examples of deviations from the mean of the distribution in a particular month: 1) more consumers of all types enter the market; and 2) more families with multiple children enter the market. The first case would affect all vehicle sales proportionately, which can be addressed by adding time dummies to equation (2):

$$\ln q_{jt} = \alpha f_{jt} + \phi_{jy} + \tau_t + \varepsilon_{jt}. \quad (3)$$

The second case might affect vehicle models disproportionately. The maintained assumption is that within model-year changes in expected fuel costs are exogenous to changes in the distribution of consumer characteristics that disproportionately affect sales. This assumption is discussed in more detail below.

To estimate equation (3), it is necessary to obtain a measure of expected fuel costs:

$$f_{jt} = \sum_{s=t}^{T+t} [\frac{1}{(1+r)^s} \frac{P_s^g}{MPG_{jy}} M_s]. \tag{4}$$

Expected fuel costs in period s equal the number of miles driven, M_s, multiplied by the cost of driving one mile, P_s^g / MPG_{jy}, where P_s^g is the expected price of gasoline in period s and MPG_{jy} is fuel economy in MPG. Total expected fuel costs, f_{jt}, equal total discounted expected fuel costs, with a discount rate of r and a vehicle life of T periods.

We assume that the price of gasoline follows a random walk, so that the expected price at any time $s > t$ is equal to the price at time t. As a result, the expected cost of driving a specific model is proportional to the current price of gasoline, divided by the vehicle's fuel economy.

We use equation (4) to replace f_{jt} in equation (3) and obtain the baseline estimating equation:

$$\ln q_{jt} = \alpha \frac{P_t^g}{MPG_{jy}} + \phi_{jy} + \tau_t + \varepsilon_{jt}. \tag{5}$$

The dependent variable is the log sales of model j in month t. The first independent variable, referred to as dollars-per-mile, is the expected cost of driving the vehicle one mile at the time of purchase; P_t^g is the seasonally adjusted price of gasoline; and MPG_{jy} is the fuel economy of model j in model-year y.[7] Section 4 describes the details of the variable construction.

The coefficient of interest is α, which is proportional to the effect on log sales of the cost of driving one mile. The parameter α is identified by time-series variation of the price of gasoline and cross-sectional variation of fuel economy. In particular, a within model-year change in the price of gasoline differentially affects expected driving costs across models. When the expected

[7] Note that α is proportional to miles driven, which is defined as the number of miles driven per year, conditional on vehicle choice. The price of gasoline may affect miles driven, but consumers can account for this effect when making their purchase decisions. Consequently, α includes the indirect effect of the price of gasoline on sales via miles driven.

price increases, the fuel costs of a vehicle with high fuel economy increase by less than the costs of a “gas guzzler”.

In addition to the monthly gasoline price variation, the inclusion of model-year intercepts is central to our empirical strategy. The model-year intercepts account for the potentially endogenous relationship among vehicle characteristics. Note that equation (5) includes the assumptions that there are no income effects and that α is constant over time and across models, but these assumptions are relaxed below.

The identifying assumption is that within model-year changes in dollars-per-mile are exogenous to other determinants of sales, including consumer preferences. Recent evidence from the new vehicles market suggests that consumer characteristics in equation (1) vary over the model-year. Copeland *et al*. (2005) and Corrado *et al*. (2006) have documented that transaction prices (the prices paid by the consumer, as distinct from the manufacturer suggested retail price, MSRP) vary substantially within the model-year. Prices decline dramatically over the course of the model-year, and sales follow a “hump-shaped” pattern, peaking in the early summer. Furthermore, sales and price profiles vary across market segments (e.g., compact cars), and many manufacturers have recently introduced incentives for specific models (Busse *et al*., 2007). In the reduced form approach used in this paper, the variable ν_{jt} in equation (1) includes changes in consumer characteristics that cause changes in transaction prices; we therefore assume that dollars-per-mile is exogenous to consumer characteristics and, thus, to transaction prices. The high frequency sales data allow us to control for slow-moving changes in consumer preferences or other factors; section 5.2 provides evidence in support of the exogeneity assumption.

2.3 INTERPRETATION OF α

The two motivations for estimating α are to address how much of the changes in market shares in Figure 1 are due to the increase in the price of gasoline, and to estimate the effect of changes in the gasoline tax on average fuel economy. For example, to calculate the effect of an increase in the price of gasoline on SUV market shares, we use equation (5) to compute counterfactual market shares in 2007 using the price of gasoline in 2002; the effect of the price increase can be inferred from the differences between actual and counterfactual market shares.

The parameter α describes the reduced form relationship between dollars-per-mile and sales, which can be illustrated by considering the example of an unexpected and permanent increase in the price of gasoline. The first effect of the price increase is that because of the reduction in disposable income, some consumers who would have purchased new vehicles decide not to purchase new vehicles. The demand curve for each new vehicle model would shift in. Assume, for the moment, that there is a proportional shift for all models; in that case, the time dummies in equation (5) would control for the inward shift. The second effect is that the expected fuel costs of all vehicles increase, but by less for vehicles with high fuel economy. Consequently, if α is negative, the demand curve of all vehicles would shift in by an additional amount, but by less for vehicles with high fuel economy. In sum, the time dummies control for the average effect of the price of gasoline on sales, and α is identified by deviations of sales relative to the mean. A negative value implies that when the price of gasoline increases, sales and market shares of vehicles with high fuel economy increase compared to vehicles with low fuel economy; the estimate of α is independent of the average effect of the gasoline price increase, which is absorbed by the time dummies.

An additional effect of a gasoline price increase is that firms may increase the relative price of vehicles with high fuel economy. Thus, the price of gasoline may affect new vehicle prices (see Langer and Miller, 2008, for evidence on prices), but because our interest lies in the reduced form relationship between dollars-per-mile and sales, it is not necessary to estimate the effect on vehicle prices.

The previous example assumed that the first effect is proportional for all vehicles. Jacobsen (2008) finds considerable evidence for substitution between new and used vehicles, which suggests that the first effect may be greater for some vehicles than for others. However, Section 5.2 suggests that dollars-per-mile is uncorrelated with substitution from new to used vehicles.

The final issue regarding the interpretation of α is that because the monthly price of gasoline and vehicle sales are used in the estimation, the estimate of α corresponds to a short-run effect of the price of gasoline on sales. In response to a permanent change in the price of gasoline, vehicle manufacturers and dealers might adjust behavior in different ways (see Bresnahan and Ramey, 1993, and Copeland and Hall, 2005, on production and pricing decisions in the short and long run). For example, following a gasoline price increase, manufacturers could redesign vehicles to achieve higher fuel economy. It is uncertain, *a priori*, how much different in magnitude the short and long run responses might be; if dealer and manufacturer inventories are large, the difference could be small.

Given the data and identification strategy used in this paper, it is not possible to directly estimate the long run effect of the price of gasoline on sales. In specifications of equation (5) that include lags of dollars-per-mile and lags of the dependent variable, the coefficients on the lags are small and not statistically significant (not reported, but available upon request). However, these results are merely suggestive. We view the baseline estimate of α as representing the short-run effect, and likely a lower bound to the long run effect. Thus, our empirical strategy is used to demonstrate a robust consumer response to a change in the price of gasoline, something that had not been previously shown in the literature.

3 DATA

The real price of gasoline is constructed using data from the Bureau of Economic Analysis's monthly consumer price index (CPI) and the price of regular unleaded gasoline from September, 1977-August, 2007. The real price of gasoline, P_t^g , is the price of gasoline divided by the CPI, with the CPI normalized to one in April of 2008. The price of gasoline is seasonally adjusted using X-12 ARIMA, which is the same model used by the Census Bureau.

Total dealer sales by vehicle model are constructed from weekly publications of Wards Automotive Reports (1978-1979) and Ward's AutoInfoBank (1980-2007). Note that the 1970s sales data do not include light trucks or imports.[8]

The monthly sales data, which span model-year 1978 through model-year 2007 (i.e., September, 1977 through August, 2007), are merged to EPA fuel economy data for the corresponding model-year.[9] Fuel economy is not available prior to the 1978 model-year, which

[8] In principle, the expansion of the sample in 1980 makes it harder to compare results from the 1970s with later years. We prefer to include the data from 1978 and 1979 to include the second major oil shock. It should be noted that in later years the results are similar for cars as for light trucks, so the expanded sample is probably not a major concern.

[9] The match is not straightforward because the two data sets are reported at different levels of aggregation. Vehicle characteristics data are reported at the "trim level" to recognize differences in the MSRP; for example, the data distinguish the 2- and 4-door versions of the Honda Accord sedan. We aggregate the characteristics data to match the model-based sales data, and calculate four statistical moments of the MPG distribution by vehicle model: minimum, maximum, mean and median. We use the mean value to estimate equation (5), but obtain similar results using other moments.

Accounts in the trade press suggest that the first month of the model-year varies somewhat across models in the data, particularly in recent years. The data do not allow us to observe the first month directly, but the specification that includes vehicle class-month interactions in Section 5.2 partially addresses potential bias that would arise if the first month of the model-year were not random. For some models that first enter the market during the sample period, it is possible to infer the first month of the model-year based on the first month in which sales are reported to Wards. Note that this measure is imperfect because some firms may not report sales of a new model when the sales prevents us from analyzing the relationship between the price of gasoline and vehicle sales in the early and middle 1970s.

Figure 2a shows the real price of gasoline and the sales-weighted average MPG from 1978-2007, plotting quarterly averages for clarity. Both series vary considerably over time. The price of gasoline increased sharply in 1979, coinciding with the major oil shock, and declined significantly in the mid 1980s. The price was then relatively stable through the 1990s, before increasing from 2002-2007. Average MPG began increasing in the late 1970s and 1980s, as the CAFE standard, which took effect in 1978, increased.[10] Fuel economy declined steadily in the 1990s and remained roughly constant thereafter. Much of the decrease was due to compositional changes, particularly the increase in sales of SUVs, which are subject to the lower CAFE standard for light trucks.

Figure 2b shows the log price of gasoline and log average fuel economy after taking first differences and removing year and quarter fixed effects. Within-year increases in the price of gasoline are associated with increases in the average fuel economy of new vehicles, particularly at the beginning and end of the sample; the relationship is much weaker in the intermediate period. The model-level estimates of equation (5), discussed in the next section, reflect these patterns.

Table 1 reports several summary statistics. The first two rows of Panel A show the mean and standard deviation of the monthly observations of the price of gasoline and model-by-month observations of MPG, roughly by decade. The real price of gasoline was lower and varied less in

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volume is small, and the first month of the model's sales in Wards may not be the same as the first month of subsequent model-years. However, the results are similar if we use this measure of the first month of the model-year.

The 1978 Energy Tax Act required that mileage ratings be reported. Note that a previous version of the paper used a fuel economy variable constructed from Wards, rather than the EPA, but the EPA data appear to be more accurate; overall, the differences across data sources are quite small.

[10] There is a sharp decline in MPG in January of 1980 because the 1970s data do not include light trucks or imports.

the 1990s than in other time periods. The MPG distribution across vehicle models is fairly stable, although the share of models with high fuel economy has increased gradually over time, as shown in Figure 3.

The last two rows in Panel A of Table 1 show dollars-per-mile and the log of model sales. Panel B shows the standard deviations of these variables after taking first differences, which is the transformation used to estimate equation (5). Even though this transformation removes much of the variation, considerable variation remains for both variables in all time periods.

4 Main Results and Implications for Market Shares and a Gasoline Tax

4.1 Effect of the Price of Gasoline on Vehicle Demand Over Time

Table 2 reports the estimate of α in equation (5). The dependent variable is the log share of sales by model and month. The main independent variable is dollars-per-mile, defined as the real price of gasoline divided by the fuel economy of the model, in MPG. The specification includes time dummies and model-year interactions. The parameters are estimated by Ordinary Least Squares (OLS). The first row of column 1 reports the estimate of α, the coefficient on dollars-per-mile. Standard deviations are shown in parentheses, clustered by model. The estimate is -12.71 with standard error 2.58, which is significant at the one percent level.

The autocorrelation function of the residuals from this specification indicates significant serial correlation, however. For that reason, column 2 reports a first-differenced specification of equation (5). The point estimate of α is similar, -10.55, and is again significant at the one percent level. All remaining specifications reported in the paper transform the variables by taking first differences.

To interpret the magnitude of α reported in column 2, consider the 2003 Acura CL (23 MPG) and the 2003 Volkswagen Jetta (32 MPG). Our estimate implies that a one dollar increase in the price of gasoline would reduce sales of the Acura by about 12 percent compared to sales of the Jetta.

While our primary interest is in explaining the trends shown in Figure 1 as well as estimating the effect of the gasoline tax on average fuel economy, we first assess whether α has changed over time. If it has, we would restrict our sample to the most recent time period to answer the questions of interest; alternatively, if α has been fairly stable, using a longer sample period would increase the efficiency of the estimate. Figure 4 shows the results of estimating a separate α for each model-year. The figure plots the 5-year moving average of the estimates with 95-percent confidence intervals indicated by the dashed lines. Several conclusions can be drawn from the figure. First, there are two time periods, from 1978-1983 and 2003-2007, in which α is negative and statistically significant. Second, during the intervening years, the estimates are close to zero but are volatile and the standard errors are much greater. The pattern suggests that it is difficult to estimate the effect of the price of gasoline on the demand for fuel economy when the price of gasoline is low or stable. This difficulty may explain the differing conclusions in the literature noted in the Introduction.

Column 3 of Table 2 reports a specification that demonstrates more succinctly the changing pattern of consumer responsiveness to the price of gasoline over time. The sample period is separated into five six-year intervals, beginning in 1978. The table reports the interaction of dollars-per-mile with a set of time period dummies. Note that there is no omitted time period in this specification, so each coefficient should be interpreted as the response during the corresponding period. The results suggest that consumer demand responds to the price of gasoline when the price is high or increasing, i.e., in the late 1970s/early 1980s and in the 2000s. In fact, the response turns out to be quantitatively similar during these times.[11] The price of gasoline had a negligible effect on sales when it was low and relatively stable in the intervening years. As in Figure 4, the coefficient estimate is weakly positive in the early 1990s, but the magnitude is smaller than in the first and last periods and the standard errors are much larger.[12] Because we are interested in understanding recent changes in market shares and the effect of a future increase in the gasoline tax, in the remaining analysis we restrict the sample to the most recent time period (2002-2007). This specification is reported in column 4, and is considered the baseline in the following discussion.

4.2 Effect of the Price of Gasoline on Market Shares of U.S. Firms and SUVs

Between August of 2002 and August of 2007 the real price of gasoline increased from $1.75 to $2.86 per gallon. During the same time period, the market share of small SUVs increased from 7.5 to 17.3 percent, while the market share of large SUVs decreased from 18.3 to 12.0 percent. At the same time, market shares of U.S. manufacturers, which rely on sales of large vehicles, declined by 20 percent. It is unclear, though, how much of the changes in market shares is related to the change in the price of gasoline.

[11] It is possible that the CAFE standard biases the results. A permanent increase in the price of gasoline would relax the constraint imposed by the standard because consumers would shift towards vehicles with high fuel economy. Firms may respond by reducing the relative prices of vehicles with low fuel economy, which would mitigate the effect of the gasoline price increase on sales. The dampening effect may be larger in the first time period, when the CAFE standards were first phased in, than in the more recent period. We use a reduced form approach to address this possibility. Vehicle type distinguishes cars from light trucks. Because the standards apply at the firm-type-year level, we estimate a specification that includes firm-type-month interactions. The results of this exercise are nearly identical to the reported results.

[12] Small and Van Dender (2007) and Hughes *et al*. (2008) provide evidence that the short and long run own price elasticity of gasoline consumption has decreased in magnitude over the past 30 years. The elasticity can be decomposed into three effects: the elasticity of miles travelled with respect to the gasoline price; the price elasticity of the size of the vehicle stock; and the price elasticity of the average fuel economy of the stock. The results reported in Small and Van Dender (2007) indicate that the decrease in the own price elasticity of consumption is due to a decrease in the price elasticity of miles traveled. The results in our paper are thus not inconsistent with the previous studies.

To answer this question we compare the actual market shares of vehicle models at the end of the sample with counterfactual markets shares, which would have occurred had the price of gasoline remained constant at the 2002 levels. Because the econometric model is static, the counterfactual market shares are computed by estimating the change in sales from their observed levels in August of 2007, assuming the price of gasoline was $1.75 instead of $2.86. Counterfactual market shares equal the ratio of counterfactual sales to the sum of counterfactual sales of models in the market. The central assumption is that the estimated value of α is an unbiased estimate of the true effect at the end of the sample, which may not be valid if the coefficient varies over time or as a function of vehicle or consumer characteristics or the price of gasoline. Although α may vary over time, Figure 4 shows that the estimate of α is uniformly negative within a fairly narrow band from 2002-2007. More importantly, Section 5 reports that the estimate is insensitive to controlling for variables that might cause α to vary, such as income or substitution to used vehicles caused by changes in the price of gasoline. Note that the main conclusions are quite similar using estimates obtained from other econometric models (section 5.1) as well as adding additional control variables (section 5.2).

We find that the increase of $1.11 per gallon caused nearly half of the decrease in the market share of large SUVs, but much less of the increase in the market share of small SUVs.[13] In calculating the effect of the price increase on the market share of U.S. automakers, we find that half of its decline can be explained by the increase in the price of gasoline. We conclude that the price of gasoline has a substantial effect on the new vehicles market, although perhaps smaller than some analysts have recently suggested.

[13] The price of gasoline affects sales in relation to the difference between a vehicle model's fuel economy and the average fuel economy in the sample. The smaller effect on small SUVs is due to the fact that the fuel economy of small SUVs is similar to the average fuel economy of models in the sample. A change in the price of gasoline therefore has a small effect on the market share of small SUVs.

4.3 Effect of a Gasoline Tax Increase on Average Fuel economy

We now relate our model to the economic policy issue of reducing gasoline consumption. The public debate has focused on raising the CAFE standard, a command-and-control type regulation that applies to new vehicles sold. Many economists, however, have argued that raising the gasoline tax instead would be a more efficient way of reducing the consumption of gasoline. A welfare comparison of the two policies depends partly on consumer demand for fuel economy (Austin and Dinan, 2005). Equation (5) estimates precisely this.

We use the estimate of α to calculate the change in average fuel economy of new vehicles due to a one dollar increase in the price of gasoline, starting from the fuel economy observed in August of 2007. The first column of Table 3 reports the difference between the counterfactual and actual sales-weighted MPG for the baseline specification in column 4 of Table 2. The standard error is reported in parentheses, calculated using the delta method.[14] The estimate of α implies that a one dollar price increase would raise average fuel economy by 1.08 MPG, which is significant at the one percent level. The elasticity of average fuel economy with respect to the price of gasoline is therefore about 0.12, which is roughly one-half of that reported by Austin and Dinan.

5 Robustness Checks

5.1 Alternative Estimation Models

As noted above, equation (5) includes several functional form assumptions. Columns 2 and 3 of Table 3 report the estimated effect of a one dollar price increase on average fuel economy using alternate estimation models that relax the main functional form assumptions in equation (5).

[14] We assume that actual market shares are measured without error, and that the only uncertainty arises from sampling variation over α . The standard errors are computed by taking the first order approximation of the mean market share, which is a nonlinear function of α .

Equation (5) was specified under the assumption that dollars-per-mile has the same effect on sales for each vehicle. By comparison, random coefficients logit models, such as BLP, allow for a separate α_i for each consumer. In that case, the effect of dollars-per-mile on the sales of a particular model is the mean α_i, weighted by the probability individuals purchase the specific model. Consequently, there is a separate α_j for each model. Researchers commonly assume that α_j is normally distributed and estimate the mean and standard deviation of the distribution. Our data include sufficient observations to simply estimate a separate α_{jy} for each model-year in equation (5) using observations from 2002-2007. Figure 5 plots a histogram of the estimated coefficients, which indicates some heterogeneity, but shows that most coefficients fall between -5 and -30. Column 2 in Table 3 uses the estimated coefficients from this specification to estimate that a one dollar increase in the price of gasoline increase raises average fuel economy by 1.20 MPG. This effect is significant at the 5 percent level and is quite similar to the baseline estimate shown in column 1.

Finally, we estimate an aggregate regression that characterizes the effect of the price of gasoline on average fuel economy:

$$\ln MPG_t = \delta \ln P_t^g + \mu_m + \tau_y + \omega_t \quad (7)$$

The dependent variable is the log of the monthly sales-weighted average MPG of all new vehicles and the first independent variable is the log monthly price of gasoline. The regression includes month and year dummies and the coefficient δ is the elasticity of average MPG to the price of gasoline. The advantage of this specification is that δ is simple to interpret, as a linear approximation to the effect of the price of gasoline on average MPG. On the other hand, the results cannot be used to answer questions pertaining to the effect of the price of gasoline on market shares of U.S. automakers and SUVs. Nevertheless, using observations from 2002-2007, we estimate equation (7) for comparison with the results reported earlier and with the previous literature. The estimate of δ is 0.063 with standard error 0.015, which is significant at the one percent level. It implies that a one percent increase in the price of gasoline raises average fuel economy by 0.06 percent. A one dollar increase in the price of gasoline raises average fuel economy by 0.51 MPG (column 3 of Table 3), which is smaller than many estimates in the literature.

5.2 Additional Specifications

The preceding sections have documented a strong relationship between the price of gasoline and consumer demand for fuel economy. We report several additional specifications that address potential omitted variables bias.

The motivation for using dollars-per-mile as a measure of fuel costs is that under a random walk assumption, the current price of gasoline is proportional to expected fuel costs. We can relax this assumption for part of the sample period by using the 6-month crude oil futures price instead of the current price of gasoline. The results are reported in column 1 of Table 4, and show that the coefficient is negative and statistically significant at the 1 percent level. The smaller magnitude reflects the greater volatility of the variable during the sample period; using the results from this specification, the implications for the effect of the price of gasoline on market shares turn out to be similar to the baseline specification.

The baseline specification uses the seasonally adjusted price of gasoline. We view this as the appropriate measure because consumers are not likely to treat all price increases equally; for example, the price of gasoline tends to be higher during the summer months than during other months and a price increase between spring and summer is not necessarily a signal of an increase in the future price. As a robustness check, column 2 uses the actual real price of gasoline rather than the seasonally adjusted price. The results are nearly identical to the baseline.

In the baseline specification we assume that dollars-per-mile is exogenous to other time-varying determinants of sales, including consumer characteristics. Sufficiently detailed data are not available to control for these variables. However, if the distribution of consumer characteristics were correlated with dollars-per-mile, it is likely that the omitted variables would be correlated among vehicles that belong to the same market segment. For example, if large and wealthy families tend to purchase vehicles in the winter, market shares of all SUVs would probably be greater in the winter.

We provide evidence supporting the exogeneity assumption in columns 3-5. Interactions of time with the model's market segment are included in these specifications, using alternative definitions of market segments. Column 3 separates models into fuel economy quintiles, and columns 4 and 5 use the vehicle market class definitions in Wards to construct 8 aggregate classes (small cars, medium cars, etc.). Column 4 includes the interaction of the market class with the calendar month and column 5 includes a full set of market class-time interactions. These specifications control for time- and market segment-varying consumer characteristics, including seasonal patterns and variables that drive the transaction price profiles observed by Copeland *et al*. (2007) and Corrado *et al*. (2006) In the three reported specifications, the main estimate is close to the baseline, although it is smaller in column 5. We conclude that the only threat to the empirical strategy would be an omitted variable that has a large effect on sales, yet is weakly correlated within a market segment. The robustness to alternative definitions of market segments suggests that this is unlikely.

6 CONCLUSION

This paper estimates the effect of the price of gasoline on the demand for fuel economy. The empirical strategy combines time series variation of the price of gasoline with cross-sectional variation of fuel economy, exploiting the fact that the effect on fuel costs of a given price change is inversely proportional to fuel economy. We control for unobserved characteristics that vary by model-year by using monthly sales and gasoline price data, combined with model-year fixed effects. We find the price of gasoline to have a significant effect on the demand for fuel economy. Our estimates imply that the increase in the price of gasoline from 2002-2007 explains much of the change in the market shares of large SUVs and of U.S. automakers. Turning to the policy question of using the gasoline tax to reduce fuel consumption, an increase in the Federal gasoline tax that raises the price of gasoline by one dollar would raise the average fuel economy of new vehicles by about 0.5-1 MPG. This result implies that fuel economy would increase only modestly under recently proposed caps on greenhouse gas emissions in the U.S., which are expected to cause the price of gasoline to increase by considerably less than one dollar per gallon by 2030 (U.S. EPA, 2009).

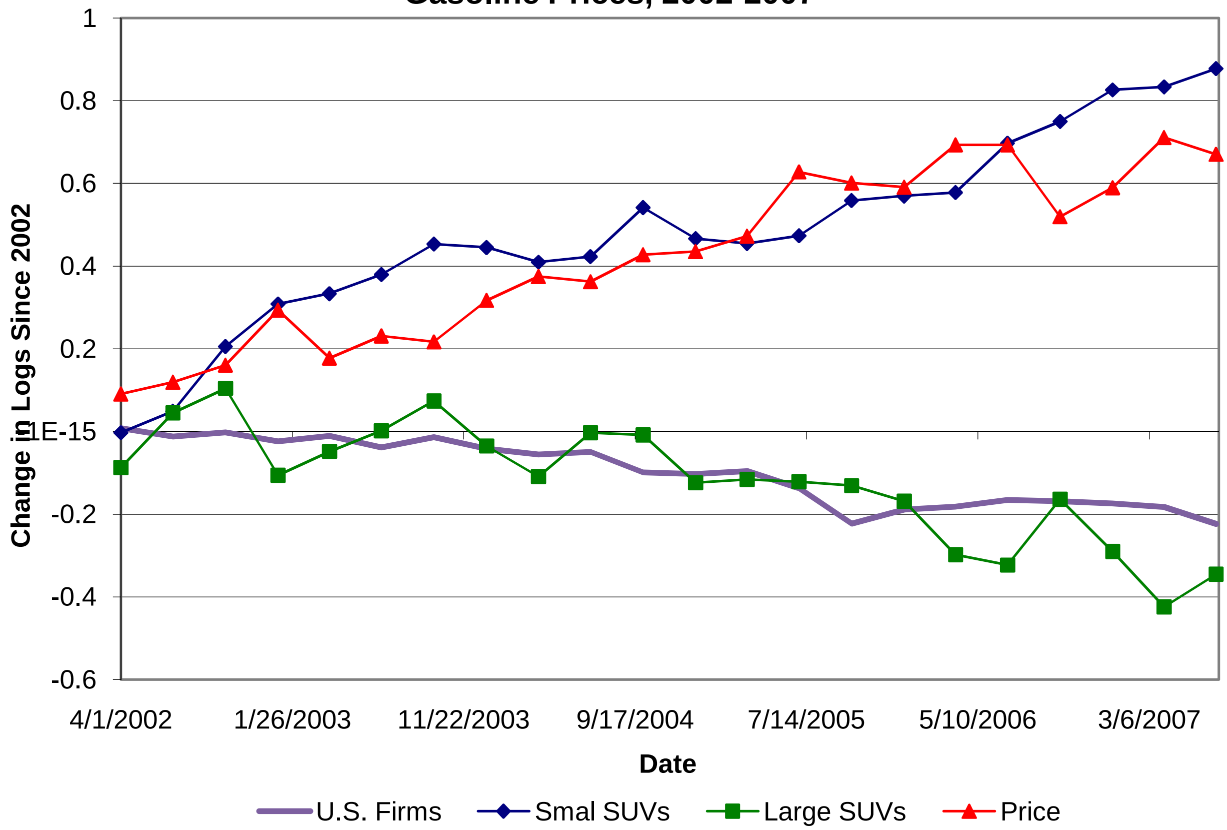
This study, as well as previous empirical work, uses a static approach in which the set of vehicle models is fixed. Furthermore, most of the literature to date only considers short run responses by automakers, dealers and consumers. However, the price of gasoline and regulations such as CAFE may also have long run effects, for example, if firms respond by offering vehicles with different fuel economy. Further work should consider a dynamic setting, in which vehicle characteristics and production decisions are endogenous.

7 REFERENCES

1. Austin, David and Terry Dinan (2005). "Clearing the Air: The Costs and Consequences of Higher CAFE Standards and Increases in Gasoline Taxes." *Journal of Environmental Economics and Management*: vol. 50, 562-582.
2. Bento, Antonio M., Lawrence H. Goulder, Mark R. Jacobsen and Roger H. von Haefen (2006), "Distributional and Efficiency Impacts of Increased U.S. Gasoline Taxes."
3. Berry, Steven, James Levinsohn and Ariel Pakes (1995), "Automobile Prices in Market Equilibrium," *Econometrica*: vol. 63(4), 841-890.
4. Boyd, J. Hayden and Robert E. Mellman (1980). "The Effect of Fuel Economy Standards on the U.S. Automotive Market: an Hedonic Demand Analysis." *Transportation Research*: vol. 14A, 367-378.
5. Busse, Meghan R., Jorge Silvo-Risso and Florian Zettelmeyer (2005). "'$1000 Cash Back': The Pass-Through of Auto Manufacturer Promotions." *American Economic Review*, vol 96(4), 1253-70.
6. Busse, Meghan R., Duncan Simester and Florian Zettelmeyer (2007). "'The Best Price You'll Ever Get': The 2005 Employee Discount Pricing Promotions in the U.S. Automobile Industry."
7. Busse, Meghan R., Christopher R. Knittel and Florian Zettelmeyer (2009). "Pain at the Pump: How Gasoline Prices Affect Automobile Purchasing in New and Used Markets."
8. Chouinard, Hayley H. and Jeffrey M. Perloff (2007), "Gasoline Price Differences: Taxes, Pollution Regulations, Mergers, Market Power, and Market Conditions," *The B.E. Journal of Economic Analysis & Policy*: vol. 7 : Iss. 1 (Contributions), Article 8
9. Copeland, Adam, Wendy Dunn and George Hall (2005), "Prices, Production and Inventories Over the Automotive Model Year."
10. Copeland, Adam and George Hall (2005), "The Response of Prices, Sales and Output to Temporary Changes in Demand."
11. Corrado, Carol, Wendy Dunn and Maria Otoo (2006), "Incentives and Prices for Motor Vehicles: What Has Been Happening In Recent Years?", *Finance and Economics Discussion Series, Board of Governors of the Federal Reserve System*, 2006-09.
12. Dubin, J. A. and D. L. McFadden (1984), "An Econometric Analysis of Residential Electric Appliance Holdings and Consumption," Econometrica: vol. 52, n2, 345-362.
13. Ellerman, A. Denny, Henry D. Jacoby and Martin B. Zimmerman (2006). "Bringing Transportation into a Cap-and-Trade Regime." MIT Joint Program on the Science and Policy of Global Change, Report No. 136, June.
14. Foster, Taft and Thomas Klier (2009). "Raising Automotive Fuel Efficiency." *Chicago FedLetter, September*. Federal Reserve Bank of Chicago.
15. Goldberg, Pinelopi Koujianou (1998), "The Effects of the Corporate Average Fuel economy Standards in the US," *The Journal of Industrial Economics*: vol. 46, n1, 1-33.
16. Hooker, Mark A. (1996). "What Happened to the Oil Price-Macroeconomy Relationship?" Journal of Monetary Economics, vol. 38, 195-213.
17. Hughes, Jonathan E., Christopher R. Knittel and Daniel Sperling (2008). "Evidence of a Shift in the Short-Run Price Elasticity of Gasoline Demand." *Energy Journal*.
18. Jacobsen, Mark (2007). Evaluating Fuel Economy Standards in a Model with Producer and Household Heterogeneity.

19. Klier, Thomas (2009). From tail fins to hybrids: How Detroit lost its dominance of the U.S. auto market. *Economic Perspectives*, Federal Reserve Bank of Chicago, 2nd Quarter, pp 2 – 17
20. Linn, Joshua (2008). "Energy Prices and the Adoption of Energy-Saving Technology." *The Economic Journal*, vol. 118, 1-27.
21. McCarthy, Patrick S. and Richard S. Tay (1998). "New Vehicle Consumption and Fuel economy: A Nested Logit Approach." *Transportation Research*: vol. 34E, 39-51.
22. McManus, Walter S. (2005). "The Effects of Higher Gasoline Prices on U.S. Vehicle Sales, Prices and Variable Profit by Segment and Manufacturer Group, 2001 and 2004."
23. Nevo, Aviv (2000), "A Practitioner's Guide to Estimation of Random-Coefficients Logit Models of Demand," *Journal of Economics and Management Strategy*: vol. 9, n4, 513-548.
24. Parry, Ian W. H. and Kenneth A. Small (2005). "Does Britain or the United States Have the Right Gasoline Tax?" *The American Economic Review*, vol. 95(4), 1276-89.
25. Small, Kenneth and Kurt Van Dender (2007). "Fuel economy and Motor Vehicle Travel: The Declining Rebound Effect." The Energy Journal, vol. 28, 25-51.
26. Tardiff, Timothy J. (1980). "Vehicle Choice Models: Review of Previous Studies and Directions for Further Research." *Transportation Research*: vol. 14A, 327-335.
27. Timiraos, Nick (2007). "The Gasoline Tax: Should it Rise?" The Wall Street Journal, August 18-19, p. A4.
28. U.S. EPA (2009). "EPA Preliminary Analysis of the Waxman-Markey Discussion Draft."
29. Ward's Automotive Yearbook, 1980-2003, Ward's Communications
30. Ward's AutoInfoBank, Ward's Automotive Group
31. West, Sarah E. (2004) "Distributional Effects of Alternative Vehicle Pollution Control `Policies," *Journal of Public Economics*: vol. 88, 735-757.

Figure 1: Changes in Market Shares of U.S. Firms and SUVs and Gasoline Prices, 2002-2007



Notes: U.S. firms include Chrysler, Ford and GM. Small sport utility vehicles (SUVs) include crossover utility vehicles, and large SUVs include all other SUVs. The figure plots the change in the log quarterly average of the real gasoline price and market shares of U.S. firms and SUVs, relative to the first quarter of 2002. The real price of gasoline is computed from the BLS and market shares are computed from Wards Auto. See Section 3 for details on data construction.

Figure 2a: Quarterly Average MPG and Gasoline Prices, 1978-2007

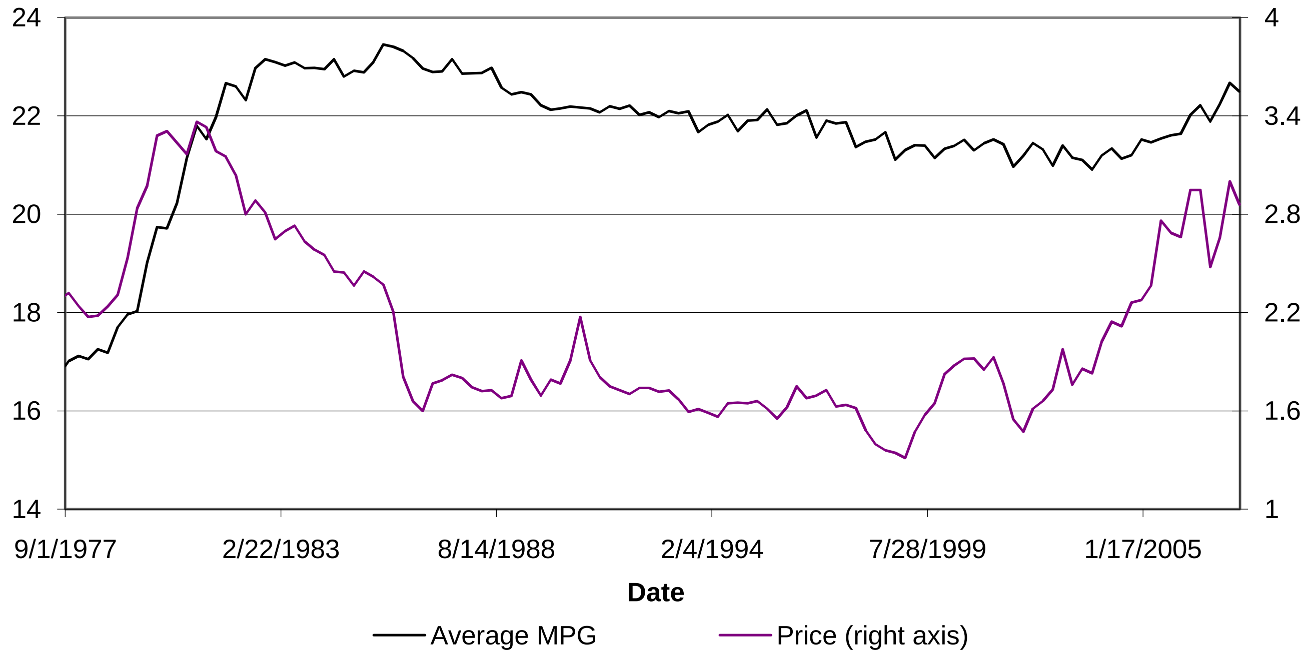
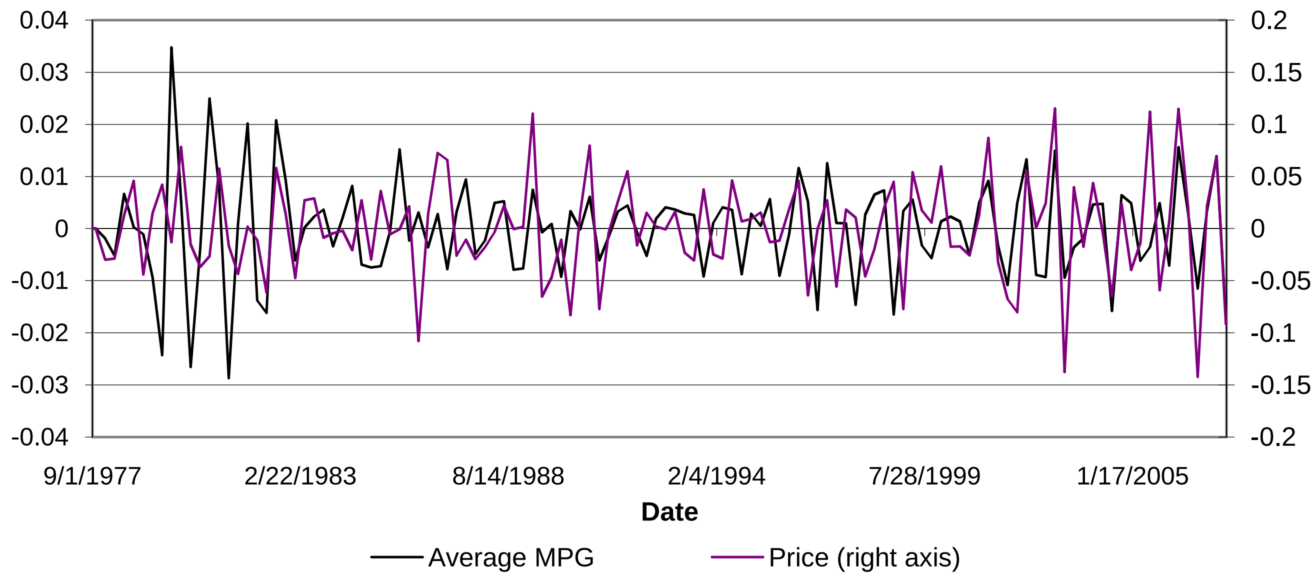
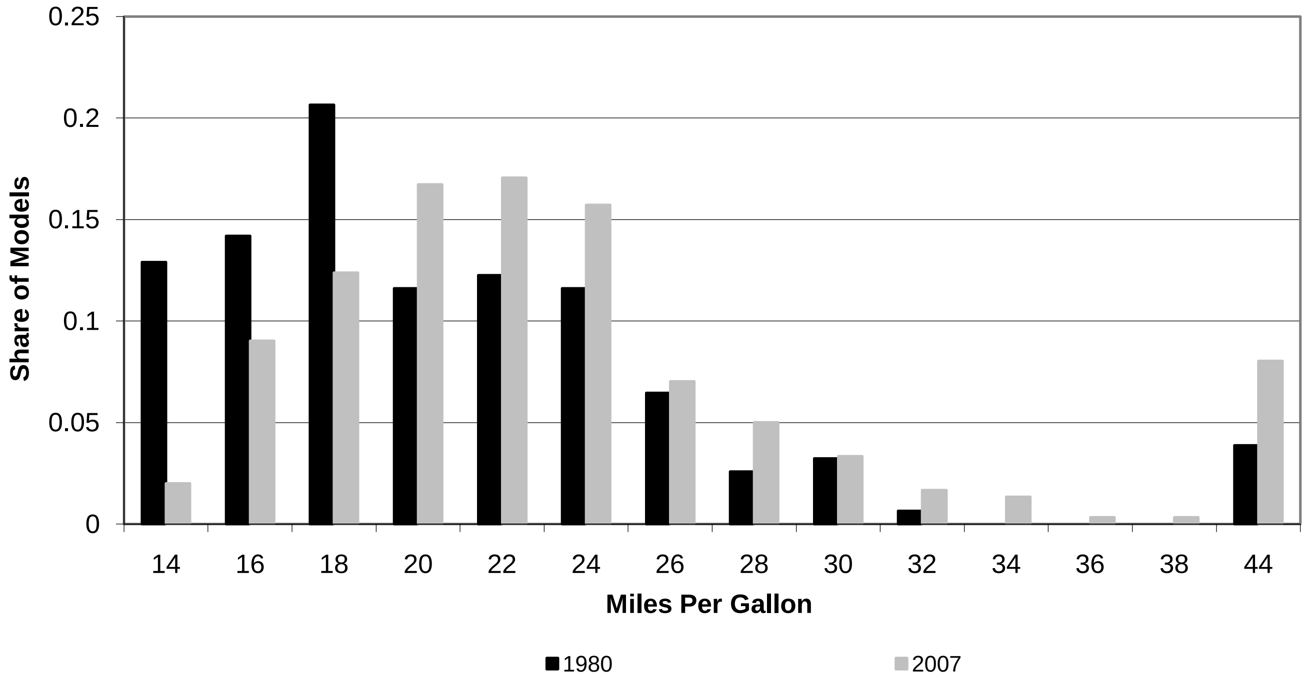


Figure 2b: First Differences, 1978-2007



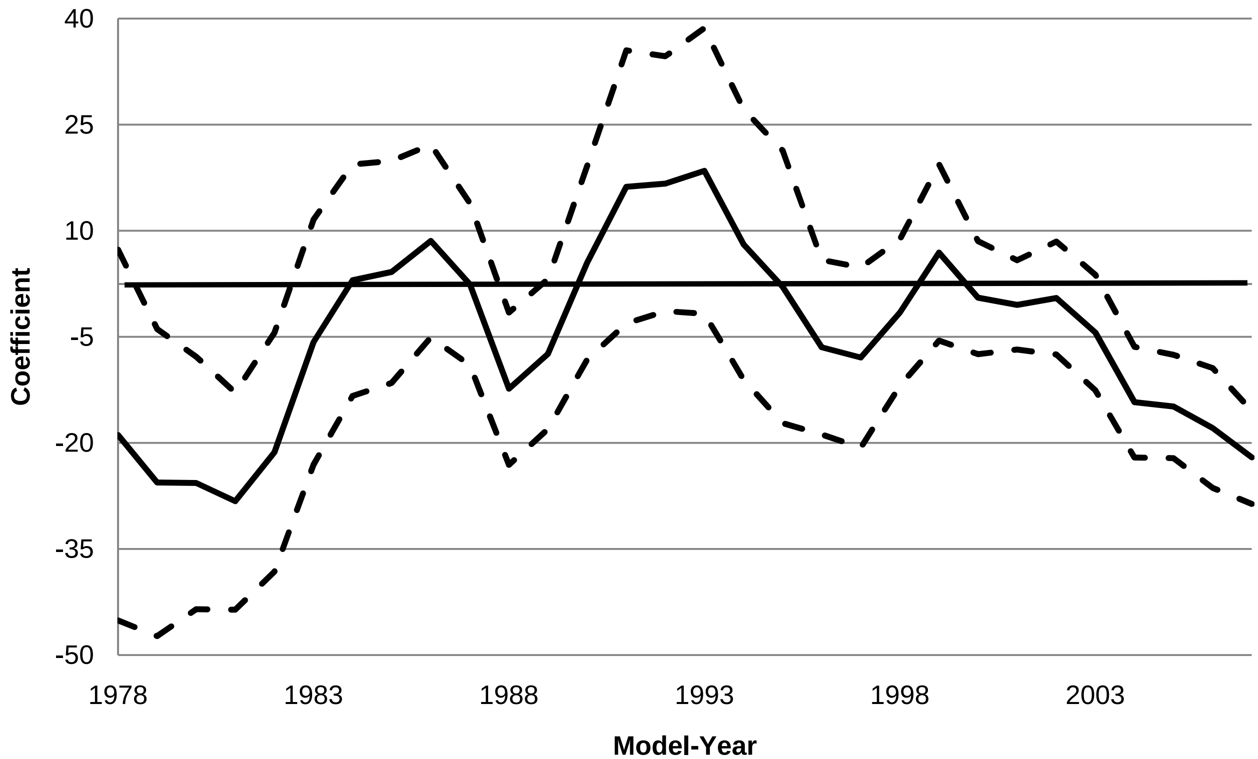
Notes: Average miles per gallon (MPG) is the sales-weighted average MPG by year and quarter. Figure 2a plots average MPG from model-year 1978-2007, and Figure 2b plots the residual of the log of average MPG, after taking first differences and removing annual means and quarter fixed effects. The real price of gasoline is the price of unleaded gasoline divided by the consumer price index, using the national average gasoline price and the consumer price index (CPI) from the Bureau of Labor Statistics. The CPI is normalized to one for April, 2008. Figure 2a plots the real price of gasoline, in 2008 dollars, and Figure 2b plots the residual of the log real price, constructed similarly to average MPG (see text for details).

Figure 3: MPG Distribution in 1980 and 2007



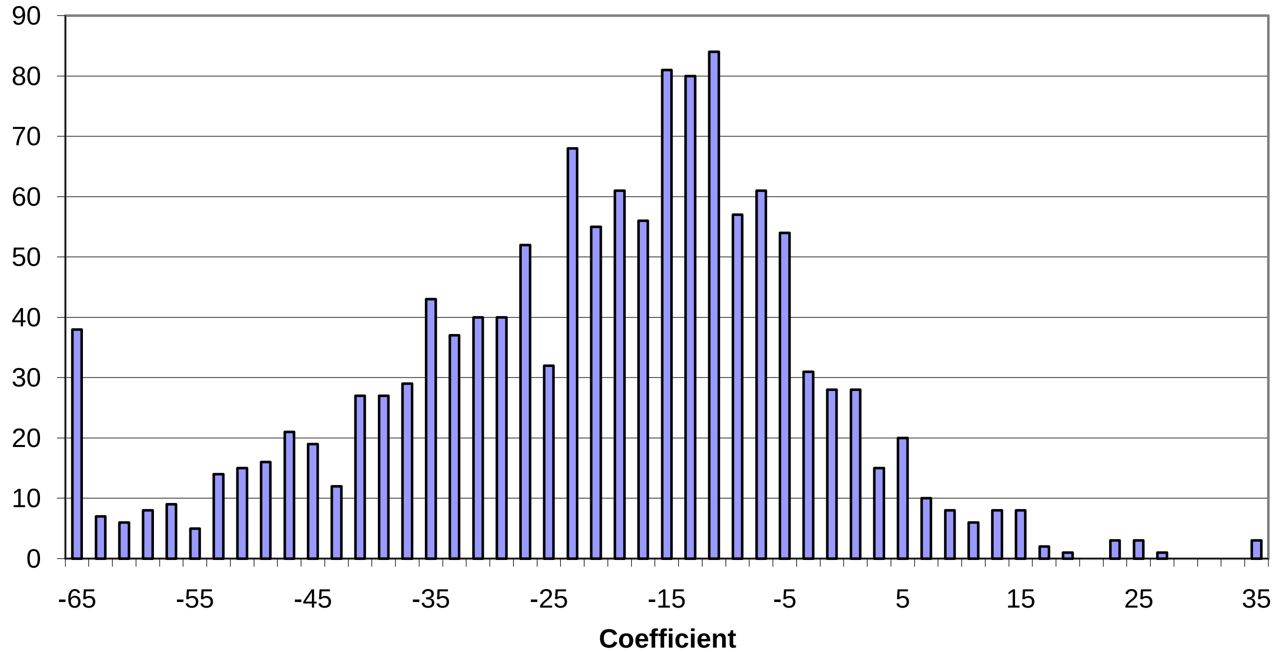
Notes: The figure plots a histogram of MPG of vehicles in the Wards database in the indicated years. The vertical axis is the share of models with positive sales for the corresponding year. The horizontal axis labels the maximum fuel efficiency of vehicles in the bin.

Figure 4: Coefficient by Model-Year, 1978-2007



Notes: The solid line is the 5-year moving average of the estimated coefficient on dollars-per-mile from equation (5). Dashed lines represent 95-percent confidence intervals.

Figure 5: Histogram of Coefficients on Dollars-Per-Mile by Model-Year



Notes: Figure 5 reports a histogram of the estimated coefficients from equation (5) with a separate coefficient on dollars-per-mile for each model-year. The sample, dependent variable and other independent variables are the same as in column 4 of Table 2. The histogram shows the number of models for which the estimated coefficient falls within the indicated bin.

Table 1:

Summary Statistics

	1978-1989	1990-1999	2000-2007
	Panel A: Sample Means and Standard Deviations		
Gasoline Price	2.43	1.66	2.12
	(0.54)	(0.16)	(0.46)
MPG	21.63	21.92	21.51
	(5.14)	(4.67)	(5.41)
Dollars-Per-Mile	0.12	0.08	0.10
	(0.04)	(0.02)	(0.03)
Log Sales	7.98	7.57	7.70
	(1.55)	(1.88)	(1.81)
	Panel B: Standard Deviations After First Differencing		
Dollars-Per-Mile	0.0032	0.0023	0.0056
Log Sales	0.36	0.39	0.39

Notes: Cells in Panel A report means with standard deviations in parentheses across observations in the indicated model-years. The first row of Panel A reports the monthly real gasoline price, computed as in Figure 2. The second row reports the average MPG of all models sold in the indicated decade. The third row reports dollars-per-mile, defined as the ratio of the price of gasoline to MPG. The fourth row reports log monthly sales by model. Panel B reports the standard deviation of the indicated variables after first differencing by model-year.

Table 2:

Effect of the Price of Gasoline on New Vehicle Sales, 1978-2007

	Dependent Variable: Log Share of Sales			
	(1)	(2)	(3)	(4)
Dollars-Per-Mile	-12.71 (2.58)	-10.55 (1.80)		-15.91 (2.54)
Dollars-Per-Mile x 1978-1983			-21.25 (5.23)	
Dollars-Per-Mile x 1984-1989			-1.04 (3.26)	
Dollars-Per-Mile x 1990-1995			7.46 (6.01)	
Dollars-Per-Mile x 1996-2001			4.98 (5.25)	
Dollars-Per-Mile x 2002-2007			-15.91 (2.54)	
Model-years in Sample	1978-2007	1978-2007	1978-2007	2002-2007
Number of Observations	71,192	64,671	64,671	15,810
R^2	0.94	0.02	0.02	0.02
First Differences?	No	Yes	Yes	Yes

Notes: Standard errors are in parentheses, clustered by model. The table reports the results of estimating equation (5) by Ordinary Least Squares (OLS). The dependent variable is the log share of sales by model and month. All variables are in first differences in columns 2-4. All specifications include month dummies and column 1 includes model-year interactions. Columns 1, 2 and 4 report the estimated coefficient on dollars-per-mile, which is constructed as in Table 1. Column 3 reports the interaction of dollars-per-mile with a set of dummy variables, which are equal to one in the indicated model-years.

Table 3:

Effect of a Price Increase on Average Fuel Economy for Alternative Specifications

	(1)	(2)	(4)
Effect of One Dollar Price Increase on MPG	1.08 (0.19)	1.20 (0.59)	0.51 (0.12)
Specification	Column (4) of Table 2	Column (1), with Separate Coefficient by Model-Year	Equation (7)

Notes: Each column reports the effect of a one dollar increase in the price of gasoline on average MPG. The effects are calculated from the indicated specifications, which use observations from model-year 2002-2007. Column 1 uses the same specification as column 4 of Table 2. Column 2 uses the same specification as column 1, except that a separate coefficient on the dollars-per-mile variable is estimated for each model-year. Column 3 reports the results of estimating equation (7). In columns 1 and 2, the calculation uses the predicted market shares of models sold in August, 2007, with and without the price increase. The standard error is in parentheses, calculated using the delta method. The effect of the price increase in column 3 is the change in average miles per gallon if the price increases by one dollar, relative to the price in August, 2007.

Table 4:

Additional Specifications

	Dependent Variable: Log Share of Sales				
	(1)	(2)	(3)	(4)	(5)
Dollars-Per-Mile	-9.39 (2.54)	-16.86 (2.08)	-14.71 (2.91)	-13.37 (2.69)	-10.71 (4.43)
Specification	Oil Futures Price	Actual Gasoline Price	Month-MPG Quintile	Month-Class Interactions	Time-Class Interactions
Number of Observations	15,810	15,810	15,810	15,799	15,799
R^2	0.02	0.02	0.02	0.03	0.06

Notes: Standard errors are in parentheses, clustered by model. The dependent variable is log market share by model and month. The sample is the same as in column 4 of Table 2. Column 1 uses the 6-month futures price of crude oil in place of the current price. Column 2 uses the actual gasoline price in place of the seasonally adjusted price. Models are assigned quintiles based on their fuel economy. Columns 3-5 report the same specification as column 4 of Table 2 but with additional controls. Column 3 includes calendar month-MPG quintile interactions. Column 4 includes calendar month- vehicle class interactions. Column 5 includes time-vehicle class interactions.

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