DISCUSSION PAPER

February 2016 ■ RFF DP 16-04

Fuel Prices, New Vehicle Fuel Economy, and Implications for Attribute-Based Standards

Benjamin Leard, Joshua Linn, and Virginia McConnell

1616 P St. NW
Washington, DC 20036
202-328-5000 www.rff.org

RESOURCES FOR THE FUTURE

Fuel Prices, New Vehicle Fuel Economy, and Implications for Attribute-Based Standards

Benjamin Leard, Joshua Linn, and Virginia McConnell

Abstract

Energy efficiency standards based on product attributes may interact with market conditions and affect the overall stringency of the standards. In this paper we analyze the interaction between gasoline prices and the redesigned and tightened federal fuel economy standards. Tighter standards will tend to reduce the effect of gasoline prices on market shares. Furthermore, under the standards a vehicle's fuel economy requirement depends on its size. Lower gasoline prices incentivize consumers to purchase new vehicles with lower fuel economy, which are typically larger and therefore face lower fuel economy requirements. Using monthly data from 1996 to 2015, we find that fuel prices have had a smaller effect on market shares in recent years than previously. This result appears to be driven by a stronger response to rising than falling or stable prices. We construct two proxies for the stringency of the standards and we find limited evidence that the standards affect the relationship between fuel prices and market shares. Using the estimated responsiveness to fuel costs from the 2008 to 2015 period, the estimates imply that the 25 percent gasoline price decrease between 2014 and 2015 had a modest effect on average fuel economy and the average fuel economy required by the standards.

Key Words: passenger vehicles, fuel economy standards, gasoline prices

JEL Classification Numbers: L62, Q4, Q5

© 2016 Resources for the Future. All rights reserved. No portion of this paper may be reproduced without permission of the authors.

Discussion papers are research materials circulated by their authors for purposes of information and discussion. They have not necessarily undergone formal peer review.

Contents

Fuel Prices, New Vehicle Fuel Economy, and Implications for Attribute-Based Standards

Benjamin Leard, Joshua Linn, and Virginia McConnell*

1. Introduction

The recent literature has demonstrated a strong connection between gasoline prices and passenger vehicle fuel economy in the United States. Klier and Linn (2010) and Busse et al. (2013) show that rising gasoline prices raise average new vehicle fuel economy, Jacobsen and van Benthem (2015) show that high gasoline prices increase scrappage of vehicles with low fuel economy, and Li et al. (2009) show that gasoline prices affect the fuel economy distribution of the on-road fleet. Collectively, these results suggest that raising gasoline taxes or introducing a carbon tax would raise the fuel economy of new vehicles and the entire on-road fleet.

In light of the recent decrease in US gasoline prices and changes in vehicle fuel economy standards, we focus on the interactions between fuel economy standards, gasoline prices and new vehicle fuel economy. In the second half of 2014 crude oil prices decreased suddenly and largely unexpectedly (Baumeister and Kilian, forthcoming). Petroleum product prices follow crude oil prices closely (CEA 2015), and between June 2014 and June 2015 the average US price of gasoline declined by almost 25 percent, from $3.77 to $2.89 per gallon; by August 2015 it had fallen to $2.34 per gallon.[1] Most projections for the coming years forecast a continuation of low prices.

Vehicle fuel economy standards are tightening and are linked more closely to vehicle attributes than they were previously. After several decades of roughly constant standards, beginning in 2005 the federal fuel economy standards have become more stringent, and they are expected to roughly double fuel economy by 2025. Their structure has changed as well. Historically, a vehicle's standard depended on its class (car or light truck), but now a vehicle's fuel economy depends not only on its class but also on its footprint (roughly, the area defined by

* Benjamin Leard, fellow, Resources for the Future (RFF), leard@rff.org. Joshua Linn, senior fellow, RFF, linn@rff.org. Virginia McConnell, senior fellow, RFF, mcconnell@rff.org.

[1] Oil and gasoline prices are from the Energy Information Administration. The oil price is the Brent spot price, which is an international benchmark price. The gasoline price is the average on-highway retail price of gasoline, including all grades.

the four wheels). Many other countries similarly base fuel economy requirements on vehicle attributes such as weight or engine size (Ito and Sallee 2014).[2] Footprint-based standards purportedly serve two purposes: they can reduce the distributional effects of the standards on different manufacturers and, second, they can prevent adverse safety consequences if manufacturers would otherwise reduce vehicle size and weight (Jacobsen 2013b). Both the tightening standards and linkage to product attributes are increasingly common among fuel economy standards and energy efficiency standards more broadly, including standards for household appliances.[3]

We argue that both the level of stringency and the linkage to vehicle attributes may affect the connection between gasoline prices and new vehicle fuel economy. We expect tighter efficiency standards to weaken the link between product sales and demand shocks—in this case, fuel price-driven demand shocks. A manufacturer facing binding standards will generally have to adjust vehicle prices to mitigate the effects of fuel prices on market shares. For example, a gasoline price decline would increase market shares of low fuel economy vehicles, causing the manufacturer's average fuel economy to fall below the standard. The manufacturer responds by raising relative prices of its low fuel economy vehicles or lowering prices of is high fuel economy vehicles to again meet the standard; as we explain in Section 3, for analogous reasons binding standards mitigate the effects of gasoline price increases. Historically, standards were binding for only a subset of manufacturers, as some manufacturers regularly exceeded the standards (Jacobsen 2013a). Consequently, binding standards would mitigate the effects of fuel prices for only a fraction of the market. However, the new standards are more stringent and are likely to be binding for all firms, which could diminish the overall effect of fuel prices on market shares.

Linking standards to product attributes also implies that demand shocks may affect the overall level of efficiency required by the standards. Declining gasoline prices may create unintended consequences for the footprint-based standards, however, by shifting market shares

---

[2] Currently, Canada and Mexico have footprint-based fuel economy standards, while South Korea, Japan, India, China and the European Union (EU) have weight-based standards.

[3] The Department of Energy Appliance and Equipment Standards Program sets energy efficiency standards based on various product attributes, depending on the nature of the product. Examples include standards for residential clothes washers that depend on loading type (e.g. top-loading versus front-loading), standards for dishwashers that depend on capacity, and standards for refrigerators that depend on freezer type (e.g. upright versus chest), defrost type (e.g. automatic versus manual), and size. See http://energy.gov/eere/buildings/standards-and-test-procedures.

toward vehicles with larger footprints and lower fuel economy requirements. The magnitude of this effect increases with the sensitivity of market shares to fuel prices; the sensitivity of fuel economy requirements to footprint; and the relationship between fuel economy requirement and vehicle class. In principle, a large change in vehicle demand toward larger vehicles with lower fuel economy requirements could substantially compromise the energy savings expected from the regulation. A similar argument applies to other attribute-based vehicle standards, such as the European Union carbon dioxide standards, which set higher carbon dioxide requirements (lower fuel economy) for heavier vehicles.[4] Hence it is vital to evaluate this effect empirically. To the best of our knowledge, this paper is the first to identify and quantify interactions between attribute demand and stringency of attribute-based fuel economy standards.

There is in fact evidence that consumers appear to be shifting toward larger vehicles with the recent decline in fuel prices. There have been numerous stories in the popular press over the past year about consumers shifting toward gas guzzlers.[5] Prior to 2014 the market share of sport utility vehicles (SUVs) decreased steadily, but this trend reversed following the gasoline price decrease; the market share of SUVs was 18 percent higher in early 2015 than it had been one year previously. The literature on new vehicle fuel economy and gasoline prices is consistent with the trends of falling gasoline prices and rising SUV market shares, but Klier and Linn (2010) show that gasoline prices had a smaller short-run effect on vehicle sales when prices were low and stable in the 1990s as compared with the period of rising prices in the early 2000s. The most recent time period, the early 2010s, is characterized by high and volatile prices—roughly the opposite of what happened in the late 1990s and 2000s.

In this paper we estimate the effect of fuel prices on new vehicle market shares. Our sample spans model years 1996 through 2015, thereby including periods of low prices, rising prices, and high and volatile prices, as well as the sharp price decline in 2014. This variation allows us to test whether market shares respond differently across periods and investigate the role of nonlinear effects and the interaction between fuel economy standards and fuel prices. The methodology is similar to that in Klier and Linn (2010, 2013). We control for unobserved vehicle characteristics by taking advantage of regular vehicle production cycles. Characteristics of a particular vehicle are typically fixed over a model year, and including model by model year

4 The EU Parliament has recently suggested converting to a vehicle footprint system for the 2020 standards to smooth the transition to more stringent emissions reduction targets.

5 See, for example, http://online.wsj.com/mdc/public/page/2_3022-autosales.html.

interactions in a linear regression controls for unobserved vehicle characteristics. We control for aggregate demand shocks using a variety of time controls. This is inherently a short-run analysis, in which the set of vehicles and their characteristics are fixed.

Consistent with Klier and Linn (2010), fuel prices had no effect on market shares when prices were low (1996–2002) and a large and statistically significant effect when prices were rising (2003–2007). When prices were high and volatile (2008–2015), they had a statistically significant effect on market shares. The fuel price decrease between 2014 and 2015 reduced new vehicle fuel economy by 0.3 miles per gallon (mpg), which offsets 37 percent of the fuel economy increase required by tighter standards between the two years. However, the effect of gasoline prices on market shares was about half as large as in the preceding period.

We find two explanations for why fuel prices had a smaller effect from 2008 to 2015 than from 2003 to 2007: market shares respond more to large and sustained price increases than to large and sustained price decreases, and during subperiods of sustained high prices, the effect of prices on market shares decreases. The 2008–2015 time period includes a total of 13 months of rapidly rising prices and 11 months of rapidly declining prices, and market shares appear to respond more to rising than to declining prices.

Turning to the interactions between fuel prices and fuel economy standards, although we expect the broader application and greater stringency of the standards to reduce the effect of fuel prices on market shares, using two proxies for the stringency of fuel economy standards, we find that the standards do not appear to explain much of the diminished effect of fuel prices on market shares. Furthermore, the recent gasoline price decrease had a relatively small effect on the overall fuel economy requirement. The requirement fell by about 0.1 mpg. This decrease eroded about 14 percent of the increase in the stringency of the fuel economy standards between 2014 and 2015, and 8 percent of the increase in stringency between 2011 and 2015. To put this effect into perspective, the agencies regulating US fuel economy and greenhouse gas emissions rates—the National Highway Traffic Safety Administration (NHTSA) and the Environmental Protection Agency (EPA)—assume that the decrease in driving costs caused by higher fuel economy erodes about 10 percent of the standards' fuel savings over the vehicles' lifetimes.[6] We note, however, that the effect we find is fundamentally different from the rebound effect. The rebound effect

[6] That is, the agencies assume a 10 percent rebound effect. Some recent studies, such as Gillingham (2014) and Linn (forthcoming), suggest rebound effects of at least 20 percent.

erodes a constant fraction of expected fuel savings from the standards. Therefore for each year that the standards are tightened, a fraction of the expected fuel savings will be eroded as households drive more. In contrast, the one-time drop in gasoline prices observed in our sample corresponds to a one-time erosion of the expected increase during the sample. There will not be further erosion of future tightening standards unless gasoline prices fall further.

The recent gasoline price decrease has had a smaller effect on the overall fuel economy requirements than on average fuel economy, primarily because there is a considerable extent of fuel economy variation across vehicles with similar footprint. Therefore, when the gasoline price falls and consumers shift toward vehicles with lower fuel economy, those vehicles do not necessarily have a lower fuel economy requirement.

These results imply that, by historical standards, the recent decline in gasoline prices has had a modest effect on new vehicle fuel economy. The results further imply that, although footprint-based standards introduce the possibility that increasing gasoline taxes or introducing a carbon tax will increase the projected fuel savings from the fuel economy standards, the increase is small relative to the overall increase in the fuel economy requirements that is expected to occur under the current rules. These conclusions are tempered, however, by the fact that they are based on a short-run analysis that does not include potential manufacturer responses of changing vehicles' designs or production plans, or long-run consumer responses if fuel prices remain low (although we observe no evidence of lagged consumer responses within the model year).

2. Data and Background

This section describes the data sources and provides summary statistics, background on US fuel economy standards, and a brief overview of recent trends in fuel prices and market shares. The dataset includes monthly sales by model and power type as well as fuel economy and other vehicle attributes, and is used in the estimation in Section 4.

2.1. Data and Summary Statistics

We obtained new vehicle sales and characteristics from Ward's Automotive. The data include monthly observations of vehicle sales and characteristics from October 1995 through August 2015. A vehicle is defined as a unique model and power type; for example, the data distinguish the gasoline and hybrid versions of the Nissan Altima. We merged the sales and characteristics data with national energy price data from the Bureau of Labor Statistics, which we converted into seasonally adjusted values measured in 2015 dollars (see the Appendix for details on the data cleaning and merging).

In the US new vehicles market, most vehicles are produced in regular production cycles. Within a production cycle, which we refer to as a model year, the manufacturer typically does not change the physical characteristics of its vehicles. Across model years, however, manufacturers can make changes that may range from offering a new set of tires to completely redesigning the interior. We define model years as beginning in October of the previous calendar year and ending in September of the current calendar year. By construction of the dataset, all vehicle characteristics are constant over the model year. In our data the timing of the model year is consistent with the typical timing of production cycles. Production of one model year often stops in late summer and resumes in early fall with the new model year.[7]

Table 1 presents summary statistics by time period. The first two rows show an increase in the number of unique models/power type over time and a corresponding decrease in average monthly sales per model/power type. Average total monthly sales (the product of the number of observations and mean sales per model/power type) were about 1.3 million from 1996 to 2007 and decreased 20 percent to 1.1 million from 2008 to 2015. The drop in sales reflects the economic recession early in this period. Sales grew again in the subsequent recovery (by about 60 percent between 2009 and 2015), but on average, monthly sales remained below the average of the earlier period.

Figure 1 provides detail on the temporal variation of these characteristics, plotting the percent change in logs since the first year of the sample. The fuel price is the sales-weighted fuel price across vehicles. For all vehicles other than plug-in electric vehicles, the fuel price is the seasonally adjusted national average real price of the corresponding fuel, obtained from the Bureau of Labor Statistics. For plug-in electric vehicles, the fuel price is a weighted average of the gasoline and electricity price, using the same weights as EPA uses to compute fuel costs for stickers that appear on new vehicle windows in car dealerships and on the website fueleconomy.gov. Fuel prices were stable in the initial period, increased from 2003 through 2007, and remained high and fairly volatile thereafter. Between model years 2014 and 2015 the real fuel price dropped almost 25 percent.

[7] The sales data do not distinguish sales by model year. Therefore, sales in a particular month may include vehicle units of more than one model year, but in any particular month the current model year accounts for most sales.

In recent years average fuel economy has increased after a long period of remaining stable or declining, and other characteristics have been increasing less quickly than in prior years. Average fuel economy was constant between 1996 and 2007, and increased about 5 percent in the final period. Horsepower, footprint, and weight increased more rapidly in the beginning of the sample period than in the end. For example, horsepower grew nearly 4 percent per year through 2004, but only 1 percent per year after 2004.

2.2. Overview of Fuel Economy Standards

Figures 2 through 5 provide some background on fuel economy standards and average fuel economy by manufacturer. Historically, standards have been set separately for cars and light trucks. From the mid-1980s until 2012 the fuel economy standard for cars was about 27.5 mpg. The fuel economy standard for light trucks was about 20 mpg from the mid-1980s through 2004 and began increasing by about 0.5 mpg per year until 2011. Since 2011 fuel economy standards for both cars and light trucks have been increasing and will continue to increase through 2025. EPA projects that by 2025 the average fuel economy of new vehicles will be double the average fuel economy in 2005. Figure 2 shows that fuel economy for both cars and light trucks was stable until the late 2000s and since then has been increasing steadily as the fuel economy standards increased.

Figure 3 shows that average fuel economy has varied considerably across manufacturers. Typically, Japanese-based manufacturers (Honda, Mazda, Mitsubishi, Nissan, and Toyota) have had higher fuel economy than US-based and other manufacturers, both for cars and light trucks. At the end of the sample period, fuel economy increased for all three categories of manufacturers.[8]

From the inception of the fuel economy standards until 2011, cars and light trucks faced uniform standards (although manufacturers had the option of complying with a footprint standard for light trucks starting in 2010). Since then, both cars and trucks are subject to footprint-based standards, such that a vehicle with a larger footprint is subject to a lower fuel economy

---

[8] In 2008 EPA changed its methodology for estimating a vehicle's fuel economy, which effectively reduced average fuel economy by about 10 percent. In figures 1 through 3 we adjust pre-2008 fuel economy to reflect the new methodology. In the empirical analysis we use the actual fuel economy reported by EPA in each year, rather than attempt to harmonize fuel economy across years, because we are interested in the effect on vehicle sales of the fuel economy that consumers observe.

requirement.[9] Figure 4 plots each vehicle's 2016 fuel economy requirement (red) and actual 2011 fuel economy (blue) against its footprint. Of course, vehicles in 2011 were not subject to the 2016 fuel economy requirements, but the figure indicates how much pressure the standards placed on the manufacturers to increase fuel economy between 2011 and 2016. The red boxes show that, in the middle of the footprint range, the fuel economy requirement decreases with footprint, but at the extremes, the fuel economy requirement is independent of fuel economy. The blue boxes show that the actual fuel economy of nearly all vehicles was well below the 2016 requirement. However, Figure 5 indicates that by 2015 the actual fuel economy of many vehicles increased considerably relative to the 2016 requirement, and that actual fuel economy for many vehicles lies above the corresponding requirement.

2.3. Recent Trends of Market Shares and Fuel Prices

As a preview of the regression analysis, we compare short-run changes in fuel prices with changes in fuel economy. Figure 6 shows the percent change of the average quarterly fuel price during a period of rising fuel prices (model years 2003–2007 in Panel A) and a period in which prices decline gradually and then fall rapidly (2012–2015 in Panel B). Along with the fuel price, the figure shows the percent change of the share of cars in total sales since the first quarter of the corresponding time period. We expect an increase in fuel prices to be positively correlated with the car market share because cars have higher fuel economy than light trucks. This positive correlation is illustrated in the overall time trends in both periods—the car market share increases in Panel A and decreases in Panel B. In addition, within the periods, the market share appears to be positively correlated with the fuel price, both when the price temporarily increases and when it decreases (such as in 2006 and 2007). Figure 7 shows similar patterns for the share of small cars in total car sales. Fuel prices are positively correlated with the market share of small cars, where a small car is defined as having a footprint below the 33rd percentile of the footprint distribution for cars.

To complement the graphical evidence of a positive correlation between fuel prices and fuel economy, Table 2 quantifies the correlation with a series of simple regressions. The regression equations take the form

---

[9] Throughout the paper, "fuel economy requirement" is used to indicate the level of fuel economy that depends on whether the vehicle is a car or truck and on its footprint. "Fuel economy standard" refers to the overall program.

$$\ln F_t = \alpha \ln p_t + \upsilon_m + \tau_y + \varepsilon_t , \quad (1)$$

where the dependent variable is the log sales-weighted monthly fuel economy, footprint, or 2016 fuel economy requirement.[10] The variable p_t is the average monthly fuel price across models, and equation (1) includes month fixed effects (υ_m), year fixed effects (τ_y), and an error term (ε_t). The month fixed effects control for seasonality, and the year fixed effects control for other factors affecting the dependent variable, such as fuel economy standards. The coefficient α is the elasticity of the dependent variable to the fuel price. We expect an increase in fuel prices to raise market shares of vehicles with higher fuel economy, raising sales-weighted average fuel economy. Because vehicles with high fuel economy tend to be smaller, we expect α to be positive when the dependent variable is fuel economy or the 2016 fuel economy requirement, and negative when the dependent variable is footprint.

The coefficient estimates in Table 2 confirm these hypotheses. Panel A indicates that a 1 percent fuel price decrease is associated with a decrease in fuel economy of 0.024 percent, an increase in footprint of 0.013 percent, and a decrease of the 2016 requirement of 0.019 percent. Panel B shows the results of estimating equation (1) in first differences. The signs of the coefficients are the same as in Panel A, but the magnitudes in Panel B are larger. The elasticities in Panel B imply that the fuel price decrease between 2014 and 2015 reduced new vehicle fuel economy 1 percent (0.35 mpg), raised footprint 0.6 percent, and reduced the fuel economy requirement 0.7 percent (0.2 mpg). By comparison, based on the vehicles in the market in 2014, the standards require an increase in fuel economy of 0.9 mpg between 2014 and 2015. Note that the elasticity of fuel economy to fuel prices is greater than the elasticity of the fuel economy requirement to fuel prices.

3. Empirical Strategy

We estimate the short-run (within model year) effect of fuel prices on average new vehicle fuel economy and the average fuel economy requirement. In the preceding section we estimated the effect of fuel prices on market-wide average fuel economy, and in this section we present our empirical strategy for estimating the effect of fuel prices on vehicle market shares.

[10] Because we use the 2016 fuel economy requirement, rather than the vehicle's fuel economy requirement in the corresponding year, changes in the sales-weighted requirement reflect changes in market shares rather than changes in stringency over time.

The disaggregated analysis allows us to investigate the potential interactions between fuel prices and fuel economy standards discussed in the Introduction.

Klier and Linn (2010) use a simple reduced-form equation to estimate the effect of fuel prices on market shares

$$\ln(q_{it} / Q_t) = \beta fc_{it} + \eta_{iy} + \tau_t + \varepsilon_{it} . \tag{2}$$

The dependent variable is the log of the market share of vehicle i in month t . The variable fc_{it} is the fuel cost per mile and is computed as the ratio of the vehicle's fuel price in month t to fuel economy of vehicle i in model year y . For all vehicles other than plug-in electric vehicles, the fuel price in the numerator is the same as that used in Figure 1, and the denominator is the fuel economy that appears on the window sticker. For example, for a gasoline vehicle the cost per mile is the ratio of the gasoline price to fuel economy. For plug-in vehicles the per-mile fuel cost is a weighted average of the gasoline and electricity cost, using the same weights as in Figure 1. It is important to note that fuel economy does not vary for a model and power type within a model year, but it may vary across model years. Under the assumption that fuel price shocks are fully persistent, the fuel cost per mile is proportional to the present discounted value of fuel costs over the vehicle's lifetime (Klier and Linn 2010). Equation (2) includes model/power by model year interactions (η_{iy}), year-month interactions (τ_t), and an error term (ε_{it}).

The coefficient of interest is β, which we expect to be negative for the following reason. Equation (2) represents the equilibrium relationship between fuel costs (a demand shifter) and market shares. We can conceive of the equilibrium relationship in equation (2) in terms of the demand curves for individual vehicles. A decrease in the fuel price lowers the cost per mile of driving for all vehicles. The time interaction (second term) in equation (2) controls for the effect of the fuel price decrease on the average cost per mile. However, the price decrease lowers the cost per mile more for vehicles with low fuel economy than for vehicles with high fuel economy. Therefore, the fuel cost of the vehicle with low fuel economy falls relative to the fuel cost of the vehicle with high fuel economy. The change in relative fuel costs causes the demand curve of vehicles with high fuel economy to shift in and the demand curves of vehicles with low fuel economy to shift out. Manufacturers may adjust vehicle prices, causing movement along these demand curves. In fact, Busse et al. (2013) show that both vehicle prices and market shares respond to gasoline prices. The coefficient β corresponds to the effect of fuel costs on market shares after allowing for any vehicle price changes that occur as a result of a fuel price change.

We expect the coefficient to be negative because a fuel price decrease raises the market share of vehicles with high fuel costs, relative to vehicles with low fuel costs. In practice, the change in market shares can arise because of a change in inventories, production, or both (we observe sales but not inventories or production, however).

The model by model year interactions play important roles in identifying β. The interactions control for all physical characteristics that do not vary over the model year. This avoids the need to control for other attributes that affect market shares such as weight and horsepower, because β is identified by within model year fuel price variation interacting with the vehicle's fuel economy. The interactions also control for unobserved demand or supply shocks that do not vary over the model year. For example, consumer perceptions about brand quality typically change little over a model year (with the obvious exception of safety recalls or the recent Volkswagen emissions scandal). We assume that fuel prices are exogenous to within model year demand shocks.

Note that, in addition to controlling for mean fuel costs, the time interactions also control for aggregate shocks to vehicle demand. In the robustness analysis we add time controls to allow for class or manufacturer-specific demand shocks.

This discussion abstracts from the interaction between fuel prices and fuel economy standards. To see the potential interaction, consider a hypothetical manufacturer that faces a binding fuel economy standard. For simplicity, suppose that the fuel economy of each vehicles is fixed in a given model year and that the manufacturer can raise its average fuel economy by reducing the relative price of the high fuel economy vehicles (Goldberg 1998). Starting from the equilibrium in which the manufacturer meets the standard, suppose the gasoline price decreases. If the manufacturer does not change vehicle prices, the market shares of its high fuel economy vehicles would decrease, causing its average fuel economy to decrease below the standard. The manufacturer therefore responds by further reducing the relative price of high fuel economy vehicles (relative to the initial equilibrium) sufficiently to raise average fuel economy to the level of the standard.

On the other hand, if fuel prices were to increase rather than decrease, the manufacturer's average fuel economy would increase above the standard if the manufacturer did not change vehicle prices. This effectively relaxes the constraint imposed by the standard and reduces the price distortion; the manufacturer raises the relative price of its high fuel economy vehicles so that it again just meets the standard. Thus, with falling or rising fuel prices, a constrained manufacturer adjusts vehicle prices to mitigate the effect of fuel prices on market shares. Which vehicles will have the greatest price adjustment to bring a manufacturer's fleet into compliance in a given period will depend on demand and supply elasticities. In addition, manufacturers do not have to fully comply with the standards in any given model year. They can bank fuel economy and emissions credits, thus allowing them to respond gradually over time to unexpected shocks (Leard and McConnell 2015). Overall, however, we expect that the cost-per-mile coefficient in equation (2) will have less of an effect on sales shares when the fuel economy standards are more stringent, because manufacturers will have to make more adjustments to vehicle prices to comply.

4. Estimation Results

4.1. Main Results

Table 3 shows the estimates of equation (2). Panel A reports the estimated coefficient on fuel costs of –7.68, which is statistically significant at the 1 percent level. The magnitude can be interpreted by comparing sales-weighted average fuel economy in model years 2014 and 2015, as predicted by equation (2). The real price of gasoline decreased from $3.50 per gallon in 2014 to $2.66 per gallon in 2015; diesel fuel prices decreased roughly proportionately. Using equation (2) to predict market shares in 2015 implies that if all fuel prices had remained at 2014 levels throughout 2015, average fuel economy in model year 2015 would have been 0.37 mpg higher than it was (Panel B).[11]

In column 1 β is identified by within model year variation in fuel prices and market shares. This specification allows for the possibility that a persistent price shock affects market shares dynamically within the model year, such as with a lag. Although it is desirable to allow for the possibility of dynamic responses, this specification raises the possibility of a biased or spurious correlation between fuel prices and market shares. For example, suppose a fuel price increase occurs early in the model year and precedes an economic downturn. Market shares may change at the end of the model year in response to the downturn and not the price decrease, which would cause a spurious correlation between fuel prices and market shares. As an alternative to estimating equation (2) in levels, we can take first differences and reestimate equation (2) omitting the model/power by model year interactions. This specification does not

[11] Specifically, the calculation replaces the predicted market share using actual 2015 monthly prices, with the predicted market share using the actual monthly prices plus the change in average fuel price between 2014 and 2015.

allow for lagged responses of market shares to fuel costs, but it would only yield biased or spurious results if an unobserved demand shock occurs in the exact same month as the fuel price shock. The results in column 2 are similar to those in column 1, reducing concerns about unobserved demand shocks that occur in the same model year as a fuel price shock.

Equation (2) imposes the assumption that the effect of fuel prices on market shares is constant over the entire sample period of model years 1996 through 2015. Klier and Linn (2010) report stronger responses of market shares to fuel prices from 2003 to 2007, when gasoline prices were increasing and high relative to previous time periods. Figure 1 suggests defining three price regimes over our sample: a) 1996–2002, when fuel prices were low and relatively stable; b) 2003–2007, when fuel prices were rising and high; and c) 2008–2015, when fuel prices were generally high and volatile. Column 3 of Table 3 reports estimates in levels and column 4 in first differences. As in Klier and Linn (2010), market shares respond more strongly in the 2003–2007 period than in the 1996–2002 period; the magnitudes for those time periods are similar to those reported in Klier and Linn (2010). In the final time period, we estimate a negative and statistically significant effect of fuel prices on market shares. This effect is smaller in magnitude than in the preceding period, but part of that difference arises from the fact that fuel prices were almost 30 percent higher in the latter time period (see Table 1), and the fuel cost coefficient scales with the fuel price. Adjusting for this fact implies that the effect of fuel costs on market shares was twice as large from 2003 to 2007 as from 2008 to 2015. Panel B shows that the decrease in fuel prices between 2014 and 2015 had a smaller effect on fuel economy if we use the estimate of β from 2008 to 2015 (columns 3 and 4) rather than the full sample (columns 1 and 2). We take the 2008 to 2015 coefficients in columns 3 and 4 as the preferred estimates, which suggest that the fuel price decrease between 2014 and 2015 reduced average fuel economy by about 0.3 mpg.

We can use the same estimation results to calculate the effect of the fuel price decrease on the fuel economy required by the US standards. We expect the fuel price decrease to reduce the fuel economy requirement as follows. Figure 4 shows that fuel economy is negatively correlated with footprint. Because lower fuel prices in 2015 raised market shares of vehicles with low fuel economy, and vehicles with low fuel economy tend to be large, the price decrease also raised the market shares of large vehicles. Figure 4 also shows that large vehicles are subject to lower fuel economy requirements, and therefore the shift toward larger vehicles reduces the overall fuel economy requirement.

Using the observed change in fuel prices between 2014 and 2015, Panel B of Table 3 shows that the average fuel economy requirement decreased by about 0.14 mpg. The magnitude of this change is smaller than that of the fuel economy change, which is consistent with the aggregate estimation results in Table 2. To provide context for this magnitude, we observe that the fuel economy requirement increased by about 0.9 mpg between 2014 and 2015. Thus the fuel price decrease between 2014 and 2015 offsets 15 percent of the increase in the fuel economy requirement over the same period. However, because fuel economy requirements tighten over time whereas the 2014–2015 gasoline price decrease was a one-time shock, it is more appropriate to compare the change in Panel B with the change in the requirements over the sample years. The fuel economy requirement increased roughly 1.6 mpg between 2011 and 2015, indicating that the fuel price decrease offset about 8 percent of that increase. For additional context, note that actual fuel economy increased by about 2.4 mpg between 2011 and 2014. The fuel economy increase between 2011 and 2014 corresponds to a 9 percent decrease in fuel consumption by new vehicles (accounting for the inverse relationship between fuel economy and fuel consumption, and assuming no rebound effect). As the bottom of Table 3 reports, the fuel price decrease between 2014 and 2015 erodes 3–4 percent of that fuel consumption decline.

In short, Table 3 shows two main findings. The first is that market shares responded to fuel prices more strongly from 2003 to 2007 than from 2008 to 2015. The second is that fuel prices affected fuel economy more than they did the fuel economy requirement. In the next three subsections, we attempt to explain these two findings.

4.2. Do the Effects of Fuel Prices Depend on Fuel Price Levels?

We continue using the market-level data from the preceding analysis and test for nonlinear relationships between fuel costs and market shares that could explain why market shares respond more to fuel costs from 2003 to 2007 than from 2008 to 2015. We consider several possible explanations for the smaller response in the latter period.

First, we allow for the possibility that market shares respond differently to fuel costs when fuel prices are rising than when they are falling. If market shares respond more to rising than to falling prices, because fuel prices were more likely to rise from 2003 to 2007 than from 2008 to 2015, this could explain the smaller effect of fuel costs in the latter period.

Table 4 shows some evidence that market shares respond more to price increases than to decreases. In column 1 we add to equation (2) the interaction of cost per mile with an indicator variable equal to one if the gasoline price increased between the previous and current months.[12] We interpret the main effect of cost per mile as the effect when fuel prices decrease and the sum of the main effect and the interaction term as the effect when fuel prices increase. In the levels regression, the coefficient on the interaction term is negative, but it is small relative to the main effect of cost per mile, and it is not statistically significant. On the other hand, the first-differenced regression indicates that market shares respond more to price increases than to decreases; the coefficient on the interaction term is large compared with the main effect and is statistically significant at the 10 percent level. The conclusion is similar if we include interaction terms based on large price increases or decreases (see columns 2 and 3). In the first-differenced regressions, large price increases have a larger effect on market shares than do other types of price changes, whereas large price decreases have (statistically) the same effect on market shares as other types of price changes.

A second possibility is that consumers respond more to persistent price changes than to temporary price changes. Gasoline prices may change because of short-term demand and supply shocks (for example, a local refinery outage) or longer-term shocks (such as the growth in nonconventional oil production). If consumers can distinguish the degree of persistence of price shocks, the consumer response to a price shock should increase with its persistence because vehicles are durable goods. To test this hypothesis, we construct an indicator variable equal to one if the price has increased for each of the past three months and add to the main regression the interaction of this variable with cost per mile. The market share response to a period of three months of rising prices is equal to the sum of the main effect and the interaction term. Column 4 of Table 4 shows that the first-differenced estimate yields a negative and statistically significant coefficient on the interaction term. In column 5 we include a similar interaction term, except defining an indicator variable for three consecutive months of price decreases rather than increases. The coefficient on the interaction term is close to zero, suggesting that market shares do not respond more to persistent price decreases than to other price shocks.[13] Considering the first two possible explanations together, we find some evidence that market shares respond more

[12] Panel A reports levels regressions, and Panel B reports first-differenced regressions; the gasoline price increases in 54 percent of months in the sample.

[13] The standard errors indicate that the price increase interaction has slightly more variation than the price decrease interaction. However, there is sufficient variation to reject the hypothesis that the two interaction coefficients are equal to one another at the 10 percent level.

to persistent price increases than to other types of price changes. However, this evidence is confined to the first-differenced regressions.

A third possibility is that, during periods of high fuel prices, the effect of fuel costs on market shares diminishes over time. This could occur if, when fuel prices begin increasing as they did in the mid-2000s, consumers react strongly to the rising prices. The strong response could occur because consumers rationally compare fuel costs of alternative vehicles or because they react to the extensive media attention that typically accompanies large fuel price increases. If prices remain high but news stories become less common, consumers may respond less to subsequent price changes than they responded to the initial price increases. Such behavior may not be rational, but it is consistent with a model in which gathering information about vehicle fuel costs is costly (Sallee 2014).

We test for this potential explanation by asking whether cost per mile has a different effect on market shares when fuel prices are high than when they are low and whether this differential changes over time. To implement this test, we define an indicator variable equal to one when the nominal seasonally adjusted gasoline price is $2.50 per gallon or greater. We interact this indicator variable with cost per mile and add the interaction to equation (2). Column 1 of Table 5 shows, using the full sample (1996–2015), that the estimated coefficient is positive either when estimating the equation in levels (Panel A) or first differences (Panel B); the coefficient is statistically significant only in the case of first differences. It is perhaps surprising that the interaction term is positive, because it indicates that market shares respond less to fuel costs when fuel prices are high, rather than more. However, estimating the same regression separately for the 2003–2007 and 2008–2015 periods in columns 2 and 3 explains this result. The interaction term is negative for 2003–2007 (column 2), although the magnitude is small and the estimate is not statistically significant. In contrast, for 2008–2015 the interaction term is positive and statistically significant, and the magnitude is large compared with the main effect of cost per mile. The results in columns 2 and 3 therefore suggest that in the 2003–2007 period the effect of fuel costs on market shares does not depend on the level of the fuel price. However, in 2008–2015 the effect at high prices has diminished.

A possible explanation for this diminished effect at high prices is that consumers grow accustomed to high prices and respond little to fuel costs when prices fluctuate but remain high. Without consumer-level data over the entire period, we cannot test this hypothesis directly, but we do provide evidence consistent with this hypothesis in columns 4–6. We construct a variable that is the count of consecutive months in which the price has been above $2.50 per gallon. The variable is zero in 2003, increases steadily through 2007, and then resets to zero when the price decreases in 2008. Columns 4–6 include the interaction of this variable with cost per mile. The interaction term is positive and statistically significant in the final time period, suggesting that the effect of fuel costs on market shares decreases the longer prices have been above $2.50 per gallon. These results are based on a price threshold of $2.50 per gallon, but the main conclusions are qualitatively similar if we use slightly higher or lower thresholds. Thus we find evidence that the effect of high fuel prices on market shares diminished over time.

4.3. Do the Fuel Economy Standards Explain the Smaller Response from 2008 to 2015?

As discussed in Section 3, binding fuel economy standards mitigate the effect of fuel prices on market shares. Because the standards were more broadly binding from 2008 to 2015 than from 2003 to 2007, this interaction between standards and fuel prices can explain the smaller response of market shares to fuel prices from 2008 to 2015. In principle we can test this hypothesis by comparing the effect of fuel prices on market shares across manufacturers according to whether the standards were binding. For example, Jacobsen (2013a) argues that the standards were binding on the US-based manufacturers (Chrysler, Ford, and General Motors), but not on the Japanese manufacturers (Nissan, Toyota, Honda) during the period of roughly stable standards. Theory suggests that market shares of vehicles sold by constrained firms respond less to fuel prices. However, comparing responsiveness across manufacturer groups would be an imperfect test because it would not account for demand or supply-side differences between US-based and other firms.

Instead, we construct two proxies for regulatory stringency. First, we create a measure of stringency that increases with the distance between a manufacturer's sales-weighted average fuel consumption rate and its sales-weighted fuel consumption requirement, as in Klier and Linn (2016).[14] Because the regressions include model by model year interactions, the manufacturer distance variable rests on the assumption that lagged levels of fuel economy are uncorrelated with subsequent within model and model year demand and supply shocks. Klier and Linn (2016) provide some evidence supporting this assumption. In addition, we note that the variable represents a static measure of stringency and does not account for credit banking, averaging across years and vehicle classes, and changes in stringency over time.

[14] The measure does not reflect a manufacturer's possible use of air conditioning credits to help achieve compliance. Also, because we exclude electric vehicles from the analysis, the measure does not include over-crediting for such vehicles.

We compute the one-year lag of this manufacturer distance variable and include its interaction with cost per mile in columns 1 and 2 of Table 6. We expect the coefficient on the interaction terms to be positive, but it is negative and not significant. In addition, the magnitude is quite small (the sample mean of the distance variable is about 0.006, which should be multiplied by the interaction coefficient to compare with the other cost per mile interactions in the table).

A second approach to identifying the interaction between standards and fuel prices is to compare the difference between the fuel economy and the fuel economy requirement of individual vehicles. To comply with binding fuel economy standards, manufacturers tend to distort vehicle prices relative to the unregulated equilibrium, such that each manufacturer reduces the relative prices of high fuel economy vehicles. The magnitude of this price distortion is proportional to the difference between the vehicle's fuel consumption rate (the reciprocal of fuel economy) and its fuel consumption requirement.[15] In responses to changes in demand, manufacturers will adjust price distortions to maintain compliance. For example, as fuel prices drop and demand for high fuel economy vehicles decreases, manufacturers have an incentive to further reduce prices for high fuel economy vehicles to maintain their sales and contribution to meeting the standard. There is no such incentive for vehicles that just meet their fuel economy requirement. Therefore, fuel prices should have a smaller effect on market shares for vehicles with fuel consumption rates that are farther above or below the requirement. Furthermore, assuming fuel prices do not affect whether the constraints are binding on manufacturers' vehicle pricing decisions, we expect a symmetric although muted effect of fuel prices on market shares, relative to the case of nonbinding standards (i.e., fuel price increases and decreases have equal and opposite effects on market shares).

---

[15] To see this, consider a manufacturer that sells a set of vehicles J and chooses the price of each vehicle to maximize profits while subject to the constraint that the sales-weighted average fuel consumption rate must exceed the standard: max $\sum_{j\in J}(p_j - c_j)q_j$ s.t. $\sum_{j\in J} q_j f_j \le F\sum_{j\in J} q_j$, where p_j is the price, c_j is marginal costs, q_j is the quantity, f_j is the fuel consumption rate, and F is the fuel consumption rate standard. If we assume all cross-price demand elasticities equal zero, the first-order condition for p_j can be rearranged to obtain $\frac{p_j - c_j + \tau(f_j - F)}{p_j} = -\frac{1}{\varepsilon_j}$, where ε_j is the own-price elasticity of demand and τ is the multiplier on the constraint. Thus the constraint causes a greater distortion for vehicles farther from the standard, all else equal.

To test this hypothesis, we compute the absolute value of the difference between the vehicle's fuel consumption rate and its fuel consumption requirement in the corresponding model year, which we define as the distance variable. We assign each vehicle to one of four distance groups that are constructed so that total sales in each group are similar to one another, as in Klier and Linn (2013). This is akin to constructing quartiles weighted by sales, and alternatively we could construct quartiles that are unweighted by sales. However, some unweighted quartiles would include many models with low sales, and the results are noisier using unweighted quartiles. We expect market shares of vehicles in the lower groups (with a smaller absolute difference) to respond more to fuel prices than vehicles in higher groups, particularly in the latter period when the standards are more binding. Demand and supply elasticities for individual vehicle models also affect the relationship between fuel prices and market shares, and this approach relies on the assumption that these elasticities are uncorrelated with a vehicle's distance from the standard; like the other stringency proxy, this distance variable represents a static measure of stringency.

In the 2003 to 2007 period, few manufacturers were constrained by the standards. Columns 3 and 4 in Table 6 show a decline for the most distant groups but the effect is small in relative terms. Columns 5 and 6 report the evidence for the 2008-2015 period. Column 5 shows the levels regression for this period and reveals some variability across groups, but the group with the largest difference from the standards shows a coefficient that is about 30 percent lower than that for the other groups. While this provides some evidence that tighter fuel economy standards reduced the effect of fuel prices on market shares, the magnitudes are not enough to explain a large share of the overall decrease in the effect of fuel prices on market shares.

Finally, in columns 7 and 8, we combine the two measures of regulatory stringency, including both the interactions of cost per mile by manufacturer distance, as well as the interactions of cost per mile by vehicle group. The results are similar to the other columns, indicating that tighter standards do not explain a large share of the decrease in the effect of fuel prices on market shares between time periods.

In summary, fuel prices have a smaller effect on market shares during the period when fuel economy standards were more stringent. We expect standards to have this effect, but we note the challenges inherent in measuring regulatory stringency. Using two proxies for stringency, we find little evidence that standards have had a large effect on the relationship between fuel prices and market shares.

4.4. Why Does Cost per Mile Affect Fuel Economy More Than It Does the Fuel Economy Requirement?

We have shown that market shares responded less to fuel costs in the 2008–2015 time period than in the 2003–2007 time period. The smaller effect causes a correspondingly smaller effect of fuel costs on the fuel economy required by the standard, compared with a counterfactual in which the response of market shares did not decline over time.

This does not explain why the 2014–2015 fuel price decrease had a larger effect on fuel economy than on the fuel economy requirement. Mechanically, the smaller effect on the requirement arises from the fact that the requirement increases less than one-for-one with fuel economy (see Figure 8).

We consider two explanations for the small effect of fuel prices on the fuel economy requirement. First, there is a fair amount of fuel economy variation across vehicles with similar footprint, as Figures 4 and 5 show. Consequently, consumers may substitute across vehicles that have different fuel economy but similar footprint and fuel economy requirements.

Second, the fuel economy requirement is independent of footprint for the largest cars and light trucks (see Figure 5). For example, all cars with footprint above 55 square feet (roughly the size of a Honda Accord or Ford Fusion) are subject to a 2016 fuel economy requirement of about 31 mpg. Consequently, although shifts in market shares for large vehicles affect average fuel economy, they do not affect the average fuel economy requirement.

To distinguish between these explanations, we construct a counterfactual scenario in which the fuel economy requirement is a linear function of footprint. This eliminates the second effect because there is no longer a flat portion of the fuel economy–footprint relationship. We construct this linear relationship such that the market-wide fuel economy requirement in 2015 was the same as in the actual market equilibrium. Then we simulate the effect of the fuel price decrease between 2014 and 2015, similarly to the simulation reported in Table 3, except that we use the linear fuel economy requirements. We find no difference between this simulation and that reported in Table 3, which supports the first explanation that consumers substitute across vehicles with varying fuel economy but similar footprint.[16]

[16] This is reasonable because there are desirable attributes that are correlated with fuel economy that can be acquired without changing the overall size of the vehicle. For example, consumers can switch to a model with a more powerful engine that is less fuel efficient.

4.5. Robustness

In this subsection we report results from other functional forms of equation (2) and relax some of the assumptions implicit in that equation. First, in Section 4.1 we noted that the levels regressions allows for lagged responses of market shares to persistent fuel price shocks over a given model year. We can explicitly include lagged responses by adding lagged fuel costs to equation (2). Columns 1 and 2 of Table 7 include one- and two-month lags, and suggest similar effects of a permanent fuel price change on market shares, compared with Table 3.

Second, the time fixed effects in equation (2) control for aggregate shocks to market shares, and we next consider the possibility of lower-level shocks. The years 2008 and 2009 were particularly turbulent for new vehicle manufacturers, as aggregate sales decreased dramatically during the economic recession. The effect of fuel costs on market shares during the recession may differ from the effect during other periods because the recession may have affected the preference distribution of new vehicle consumers; for example, interest rates increased during the recession, which may have caused consumers with low credit ratings to postpone vehicle purchases. To allow for this possibility, we omit the model years 2008 and 2009 in column 3 of Table 7. The levels estimate in Panel A is smaller than using the full 2008–2015 sample (see column 3 of Table 3), but the first-differenced estimate is similar to the estimate using the full 2008–2015 sample period. There is thus mixed evidence that fuel costs had a different effect on market shares during the recession. Nevertheless, we conclude that fuel costs had a smaller effect after 2007, regardless of whether we include the recession years.

Although equation (2) controls for aggregate demand shocks, it does not control for class or manufacturer-level demand shocks. Such shocks would bias the estimate of β if they are correlated with fuel prices or fuel costs, after controlling for average demand over the model year. For example, a safety recall in the middle of the year would affect some manufacturers more than others. We allow for the possibility of such shocks by adding further time controls to equation (2). We construct a linear monthly time trend that increases from zero to 11 each model year, and we add a time trend by class interaction in column 4 and time trend by manufacturer group interactions in column 5. The results are unaffected by adding these controls, reducing concerns about omitted demand shocks.

Third, equation (2) imposes the assumption that fuel costs affect market shares proportionately for all vehicles. As an alternative specification, we can also allow β to vary by fuel economy group g

$$\ln(q_{it} / Q_t) = \beta_g fc_{it} + \eta_i + \tau_t + \varepsilon_{it} \,. \tag{3}$$

Equation (3) allows the effect of fuel costs on market shares to vary by fuel economy group and is therefore more flexible than equation (2). We define five fuel economy groups such that the total sales of each group are approximately equal. We estimate a separate β for each fuel economy group and report the estimates in Table 8 for the full sample (columns 1 and 2) and 2008–2015 (columns 3 and 4). Overall, we find little evidence that the coefficients vary across fuel economy groups. The first-differenced results (columns 2 and 4) are noisier than the levels results, likely indicating that there is insufficient variation to identify all the fuel cost coefficients after first-differencing the data.[17]

Finally, in other analysis not reported in Table 8 (but available on request), we test whether cost per mile affects market shares of cars differently than market shares of light trucks. We do not find evidence of a large or statistically significant difference between the effects for cars and for light trucks.[18]

5. Conclusions

Coinciding with the sharp decline in global crude oil prices, US gasoline prices decreased by about 25 percent between mid-2014 and mid-2015. During this period there have been numerous media stories about new vehicle consumers shifting to larger vehicles with lower fuel economy. During the period of high but volatile gasoline prices during 2008 to 2015, we find that the effect of fuel costs on market shares was smaller than it was compared with the preceding period. In other words, although recent gasoline price decreases have had a noticeable effect on market shares, the effect of rising gasoline prices in the mid-2000s was actually about twice as large. We provide suggestive evidence that the diminished effect arises because a) market shares respond more to price increases than to price decreases; and b) market shares respond less following a prolonged period of high fuel prices.

[17] The lack of precision of the interaction between cost per mile and the highest mpg group can partially be explained by the significant number of models in this group that are plug-in hybrids and electric vehicles. For these vehicles there is little within model and within model year variation in cost per mile because national electricity prices are stable within a given model year.

[18] We have also tested whether cost per mile affects market shares differently for hybrids, electrics, or other types of vehicles (see Appendix Table 1). There is insufficient variation to identify such differential effects, however.

We also consider whether the increase in stringency that occurred between the 2003-2007 and 2008-2015 time periods diminished the effect of fuel prices on market shares. We construct two proxies for the stringency of fuel economy requirements that rely on the exogeneity of a vehicle's fuel economy to subsequent demand or supply shocks. Using the two proxies it does not appear that the standards have caused a large share of the overall decline in the effect of fuel prices on market shares across time periods.

We note four main caveats to these conclusions, all of which point to future research. First, the analysis holds fixed the set of vehicles and their characteristics. Manufacturers may respond to a sustained fuel price change by redesigning their vehicles to change fuel economy, introducing new vehicles, or eliminating other vehicles. In addition, manufacturers typically make production plans for a model year and have some flexibility to change plans during the model year. In general, one might expect the cost of changing production to be lower across model years than within model years. These considerations suggest that gasoline prices may affect market shares more in the long run than in the short run. Anecdotal evidence suggests that manufacturers have become more adept at changing vehicle production within a model year, which would suggest that the difference between the short- and long-run manufacturer responses has decreased over time. Future research can assess the long-run effects of gasoline prices and test whether the responses have changed over time.

Second, rising fuel prices appear to have a larger effect on market shares than do falling prices. Although we observe multiple years of steadily rising prices, we only observe about one year of falling prices at the end of the sample. Given the evidence that market shares respond more to sustained price increases than to other price changes, it is possible that market shares will continue to respond to the 2014–2015 price decrease if prices remain low, as current forecasts predict. Such low prices may imply a new price regime, beyond those considered in this paper and future analysis of fuel prices and market shares could test this hypothesis.

Third, we have documented a smaller effect of fuel prices in 2008–2015 than in 2003–2007 and provide evidence consistent with two explanations. The analysis is based on market-level data, and the proposed explanations should be explored further using consumer-level data.

Fourth, due to the lack of data we do not analyze the interaction of the new vehicle market with used vehicle market and vehicle scrappage. Falling gasoline prices may lead to pricing strategies of new vehicle manufacturers based on interfirm competition and competition with the used vehicle market. While we implicitly capture this effect in our new vehicle fuel economy estimates, we do not measure how fuel economy in the used vehicle market responds to fuel prices. Furthermore, falling gasoline prices prolong the lifetime of vehicles with low fuel economy relative to vehicles with high fuel economy (Jacobsen and van Benthem, 2015). These effects alter the composition of the entire fleet, possibly interacting with the effects that we identify in the new vehicle market.

Finally we note that although we find moderate effects of gasoline prices on the stringency of US fuel economy standards, demand shocks to vehicle footprint, weight, or other attributes could have differing effects in other countries. Whether such shocks would dramatically deteriorate or bolster the expected energy savings stemming from the standards remains a promising area of research.

6. References

Baumeister, C., and L. Kilian. Forthcoming. Understanding the Decline in the Price of Oil since June 2014. *Journal of the Association of Environmental and Resource Economists*.

Busse, M., C. Knittel, and F. Zettelmeyer. 2013. Are Consumers Myopic? Evidence from New and Used Car Purchases. *American Economic Review* 103: 220–56.

CEA (Council of Economic Advisers). 2015. *Annual Report of the Council of Economic Advisers*. Washington, DC: Government Printing Office.

Gillingham, K. 2014. Identifying the Elasticity of Driving: Evidence from a Gasoline Price Shock in California. *Regional Science and Urban Economics* 47: 13–24.

Goldberg, P. K. 1998. The Effects of the Corporate Average Fuel Efficiency Standards in the U.S. *Journal of Industrial Economics* 46: 1–33.

Ito, K. and J. Sallee. 2014. The Economics of Attribute-Based Regulation: Theory and Evidence from Fuel Economy Standards. NBER Working Paper 20500. Cambridge, MA: National Bureau of Economic Research.

Jacobsen, M. 2013a. Evaluating U.S. Fuel Economy Standards in a Model with Producer and Household Heterogeneity. *American Economic Journal: Economic Policy* 5: 148–87.

———. 2013b. Fuel Economy and Safety: The Influences of Vehicle Class and Driver Safety. *American Economic Journal: Applied Economics* 5: 1–26.

Jacobsen, M., and A. A. van Benthem. 2015. Vehicle Scrappage and Gasoline Policy. *American Economic Review* v115: 1312–38.

Klier, T., and J. Linn. 2010. The Price of Gasoline and New Vehicle Fuel Economy: Evidence from Monthly Sales Data. *American Economic Journal: Economic Policy* 2: 134–53.

———. 2013. Fuel Prices and New Vehicle Fuel Economy—Comparing the United States and Western Europe. *Journal of Environmental Economics and Management* 66: 280–300.

———. 2016. The Effect of Vehicle Fuel Economy Standards on Technology Adoption. *Journal of Public Economics* 133: 41–63.

Leard, B., and V. McConnell. 2015. New Markets for Pollution and Energy Efficiency: Credit Trading under Automobile Greenhouse Gas and Fuel Economy Standards. Discussion paper 15-16. Washington, DC: Resources for the Future.

Li, S., C. Timmins, and R. H. von Haefen. 2009. How Do Gasoline Prices Affect Fleet Fuel Economy? *American Economic Journal: Economic Policy* 1: 113–37.

Linn, J. Forthcoming. The Rebound Effect for Passenger Vehicles. *Energy Journal*.

Sallee, J. 2014. Rational Inattention and Energy Efficiency. *Journal of Law and Economics* 57: 781–820.

Data Appendix

A. Energy Price Data

To construct our measure of cost per mile, we obtained monthly national average energy prices from the Bureau of Labor Statistics. We collected three sets of energy prices:

1. Gasoline, unleaded regular, dollars per gallon
2. Automotive diesel fuel, dollars per gallon
3. Electricity, dollars per 500 KWH

We also collected a seasonally adjusted monthly consumer price index (CPI). We converted each panel of nominal prices into real, seasonally adjusted prices using the CPI data and a seasonal adjustment X-12 ARIMA software, which is used by the US Census Bureau.

B. Data Cleaning and Merging

We took several steps to clean and merge the Wards sales data, characteristics data and the BLS energy price data to complete our dataset. The first task was to clean the Wards characteristics data that had a few missing values for fuel economy and vehicle footprint. For these missing values, we used those reported by Edmunds.com.

The second task was to merge the Wards vehicle sales data with the cleaned Wards vehicle characteristics data. Wards provided us with monthly new vehicle sales by make/model/power type, e.g. Honda Civic Gasoline and new vehicle characteristics by model year/make/model/body type/trim, e.g. 2009 Honda Civic Coupe DX. This merging required two decisions. First, we aggregated the vehicle characteristics data to the model year/make/model/power type level by taking the vehicle characteristics of the base model for each model year/make/model.[19] Since the 2009 Honda Civic Coupe DX is the least expensive Honda Civic gasoline powered trim, its characteristics are assigned to the Honda Civic Gasoline 2009 model year sales data. Second, we assigned monthly sales to a particular model year model by power type.

[19] We assumed the base model to be the least expensive body type/trim for each model. In virtually all cases, this observation was the first body type/trim listed for a given model in the Wards data.

The third task was to merge the Wards data with the BLS energy price data. We assigned real, seasonally adjusted energy prices to each vehicle according to the vehicle's power type. Gasoline and hybrid vehicles were assigned gasoline prices, diesel vehicles were assigned diesel prices, and electric vehicles were assigned electricity prices. We assigned an energy price to plug-in hybrid vehicles using a weighted average of gasoline prices and electricity prices. We calculated weights for each model year/make/model based on the fraction of miles driven in electricity mode implied by fuel economy stickers from fueleconomy.gov. Current fuel economy stickers provide information on combined fuel economy in electricity mode, combined fuel economy in gasoline mode, assumed electricity and gasoline prices, an assumed annual vehicle miles traveled and an estimated annual fuel cost. We formed a set of two equations for each vehicle to solve for the implied fraction of miles driven in electricity mode: An annual miles traveled equation and an annual fuel cost equation. We then solved for the unknowns in these two equations – miles traveled in electricity mode and miles traveled in gasoline mode – for each plug-in model. The implied fraction of miles driven in electricity mode is then the implied miles driven in electricity mode divided by the assumed total annual miles traveled. Table A1 provides the implied fraction of miles driven in electricity mode.

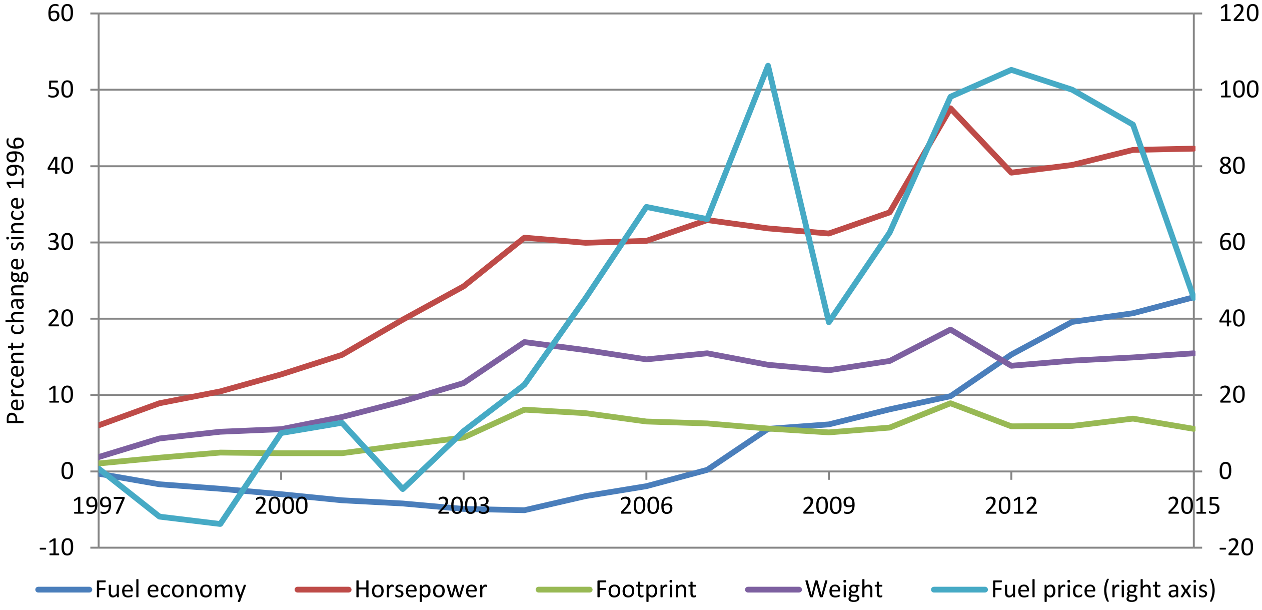
Table A1. Implied Fraction of Miles Driven in Electricity Mode

Model Years	Make	Model	Fraction of Miles Driven in Electricity Mode
2014, 2015	BMW	i8	0.40
2014, 2015	Cadillac	ELR	0.50
2011-2015	Chevrolet	Volt	0.46
2013-2015	Ford	C-Max	0.47
2013-2015	Ford	Fusion	0.47
2013-2015	Honda	Accord	0.25
2012-2015	Toyota	Prius	0.28
2015	Porsche	918 Spyder	0.30
2015	Porsche	Cayenne	0.38
2014-2015	Porsche	Panamera	0.30

Figures and Tables

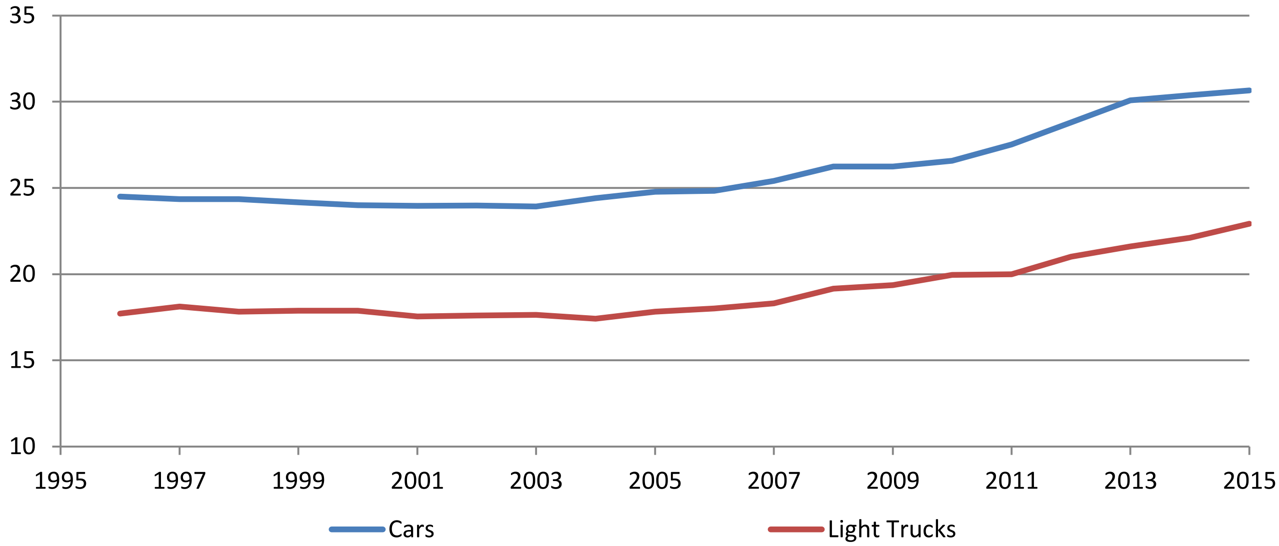
See following pages.

Figure 1. Changes in Vehicle Characteristics



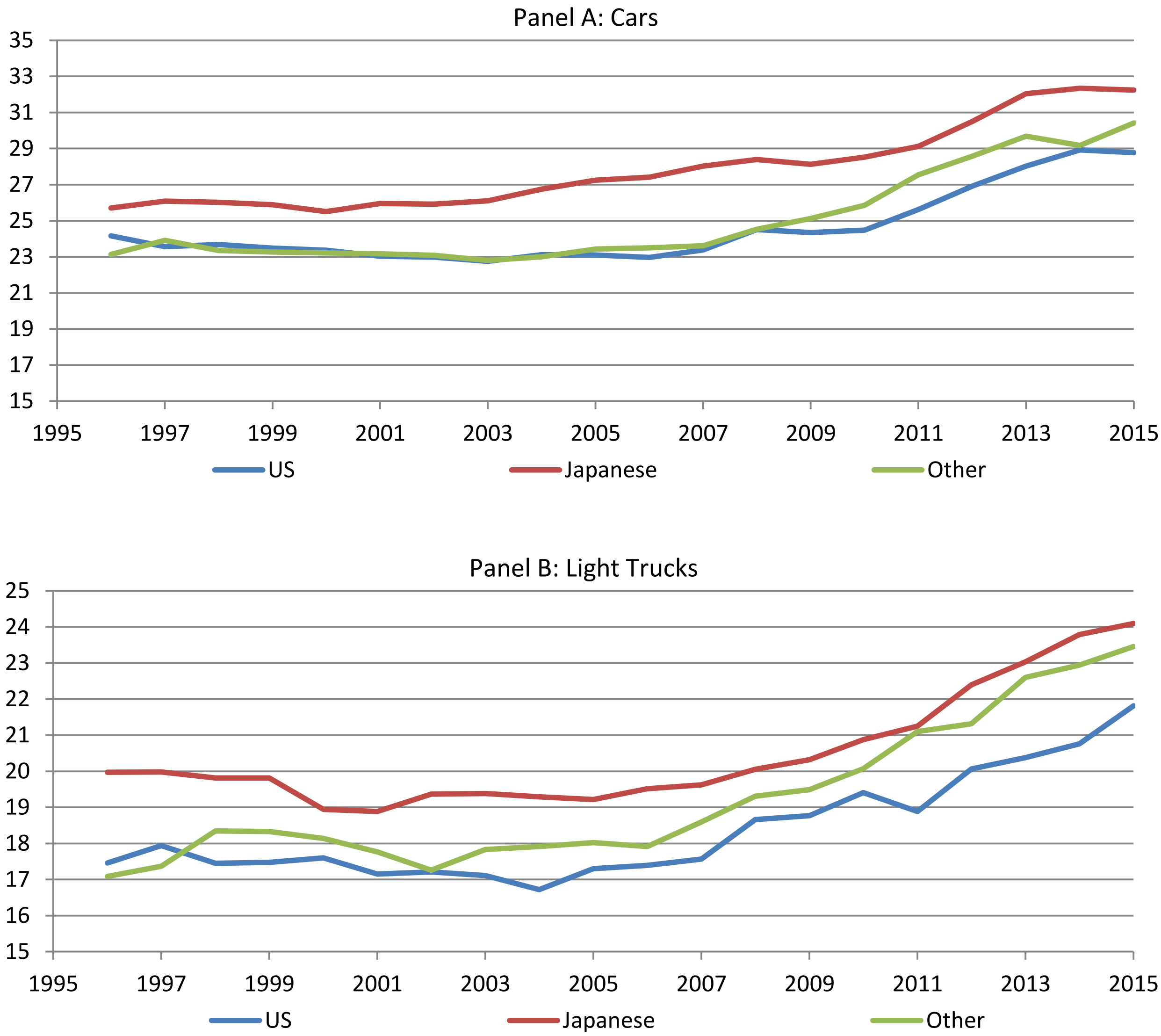
Notes : Sales-weighted means of fuel economy, horsepower, footprint, weight, and fuel price are computed by model year. The figure plots the percent change in the sales-weighted mean since the 1996 model year. Prior to 2008 fuel economy is computed using the post-2008 EPA methodology.

Figure 2. Average Fuel Economy for Cars and Light Trucks by Model Year



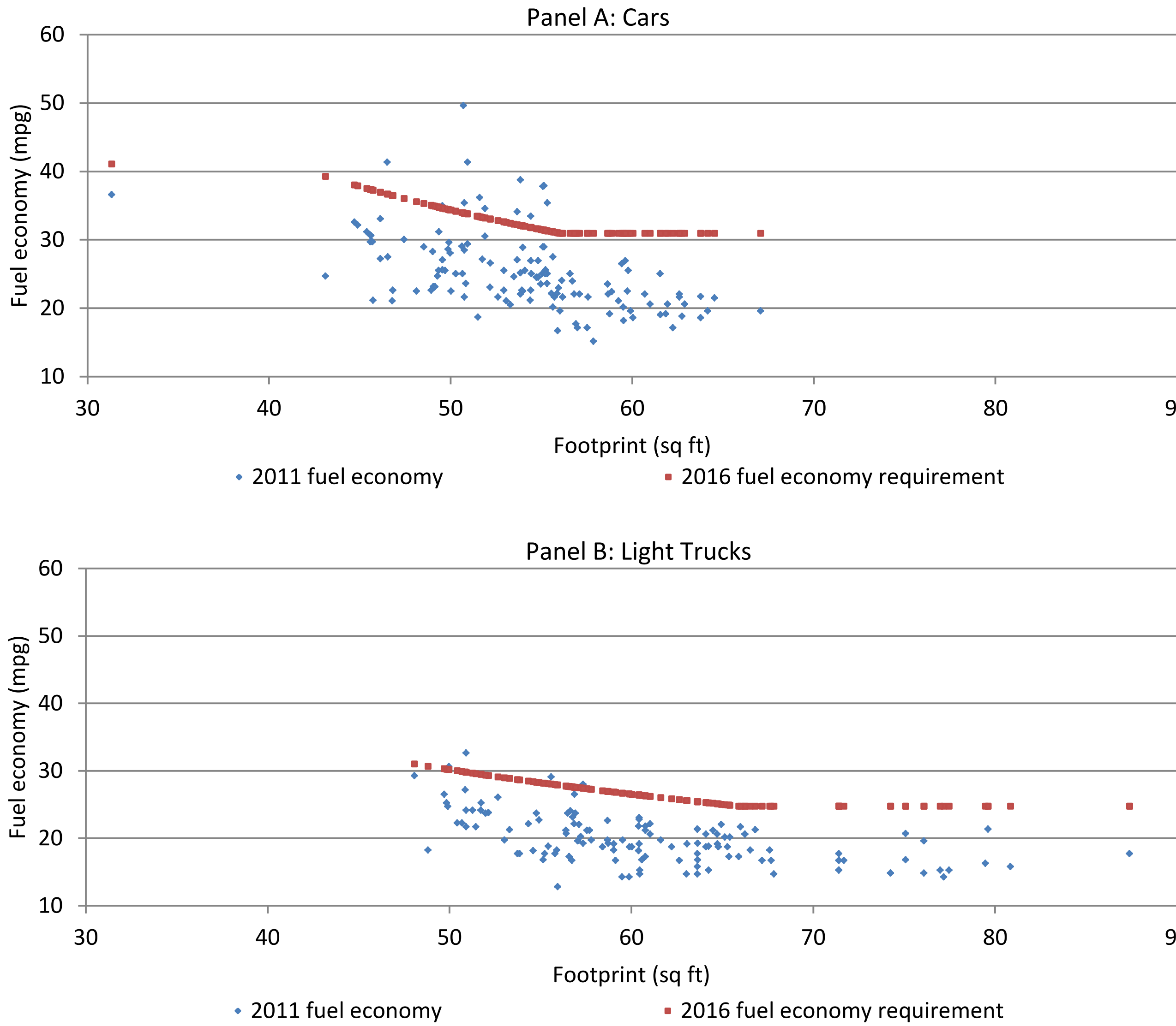
Note : The figure plots the sales-weighted average fuel economy for cars and light trucks by model year. Prior to 2008 fuel economy is computed using the post-2008 EPA methodology.

Figure 3. Fuel Economy by Manufacturer Home Location



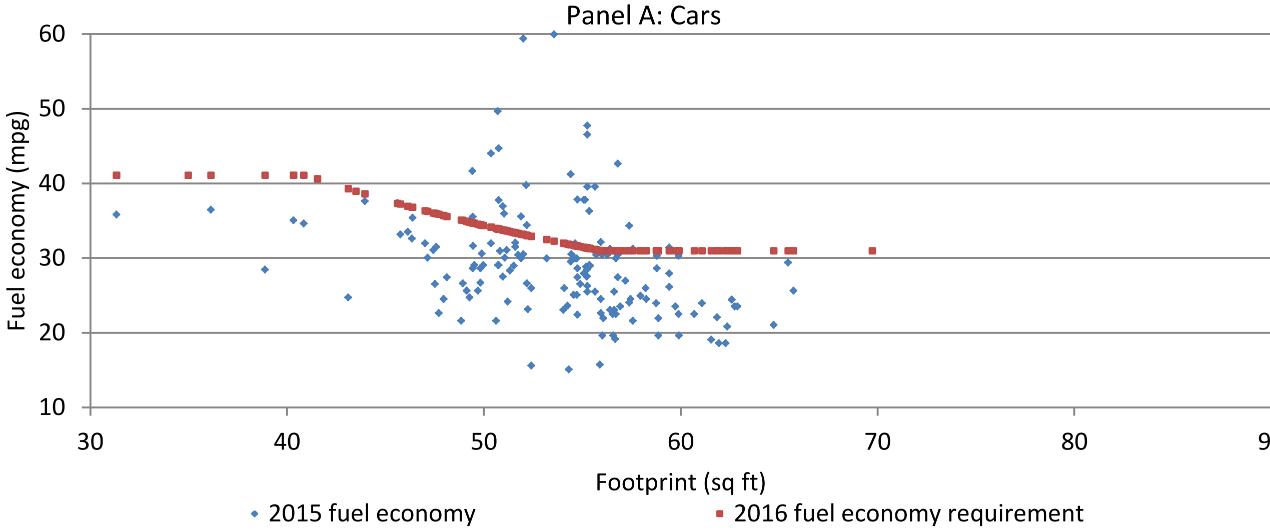
Notes : The two panels plot the sales-weighted average fuel economy by manufacturer group for cars (panel A) and light trucks (panel B). US-based manufacturers include Chrysler, Ford, and General Motors. Japanese-based manufacturers include Honda, Mazda, Mitsubishi, Nissan, and Toyota. Prior to 2008 fuel economy is computed using the post-2008 EPA methodology.

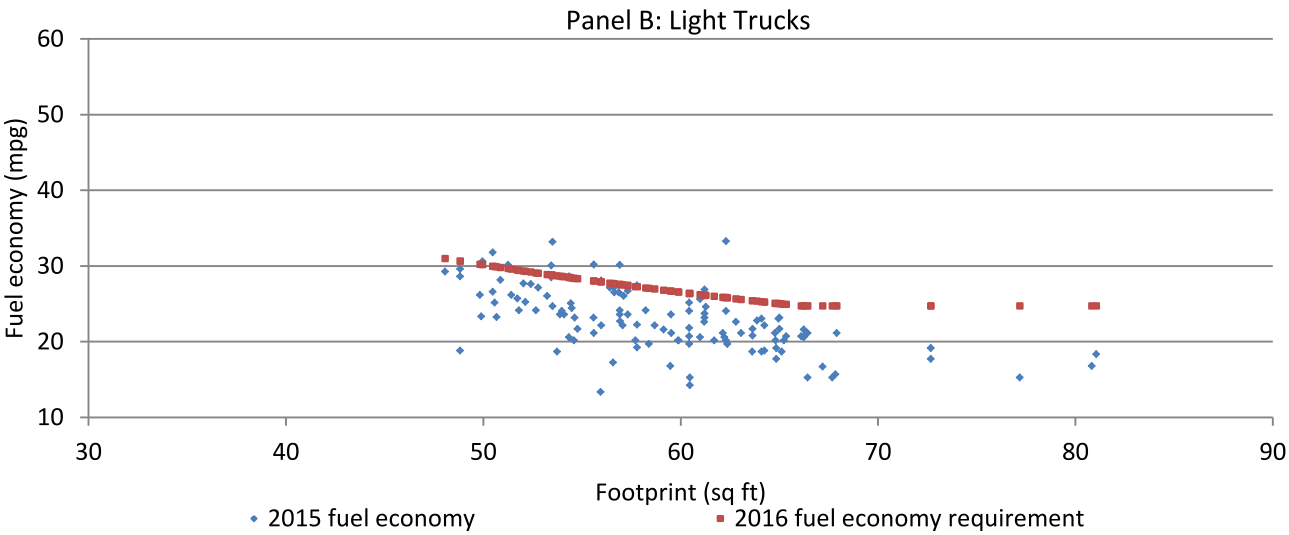
Figure 4. 2011 Fuel Economy and 2016 Standard vs. Footprint



Notes : The samples include all car models and power types in panel A and all light truck models and power types in panel B for the 2011 model year. For each model and power type, the figure plots its actual fuel economy (blue) and 2016 fuel economy requirement (red) in miles per gallon (mpg) against the corresponding footprint in square feet (sq ft).

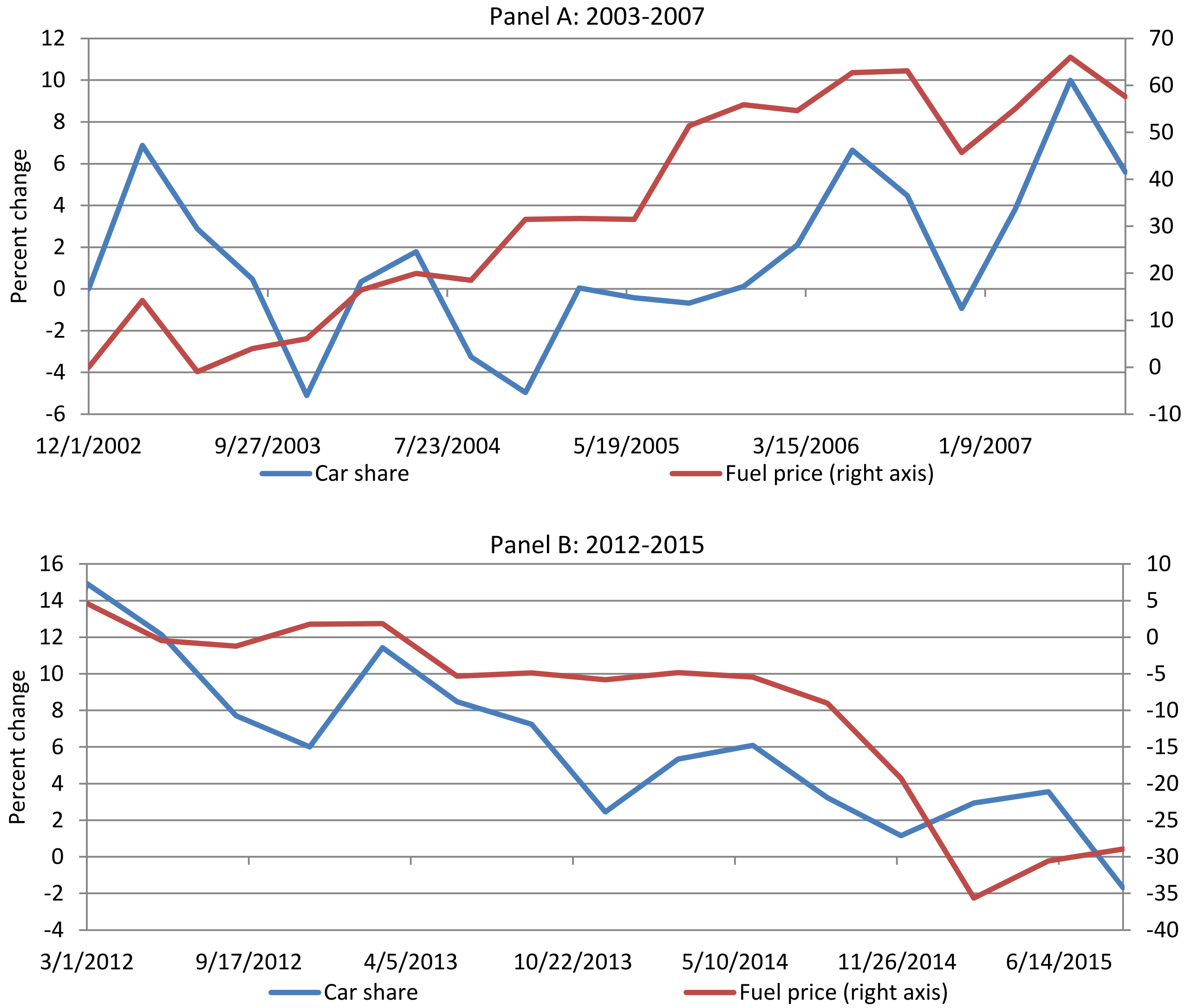
Figure 5. 2015 Fuel Economy and 2016 Standard vs. Footprint





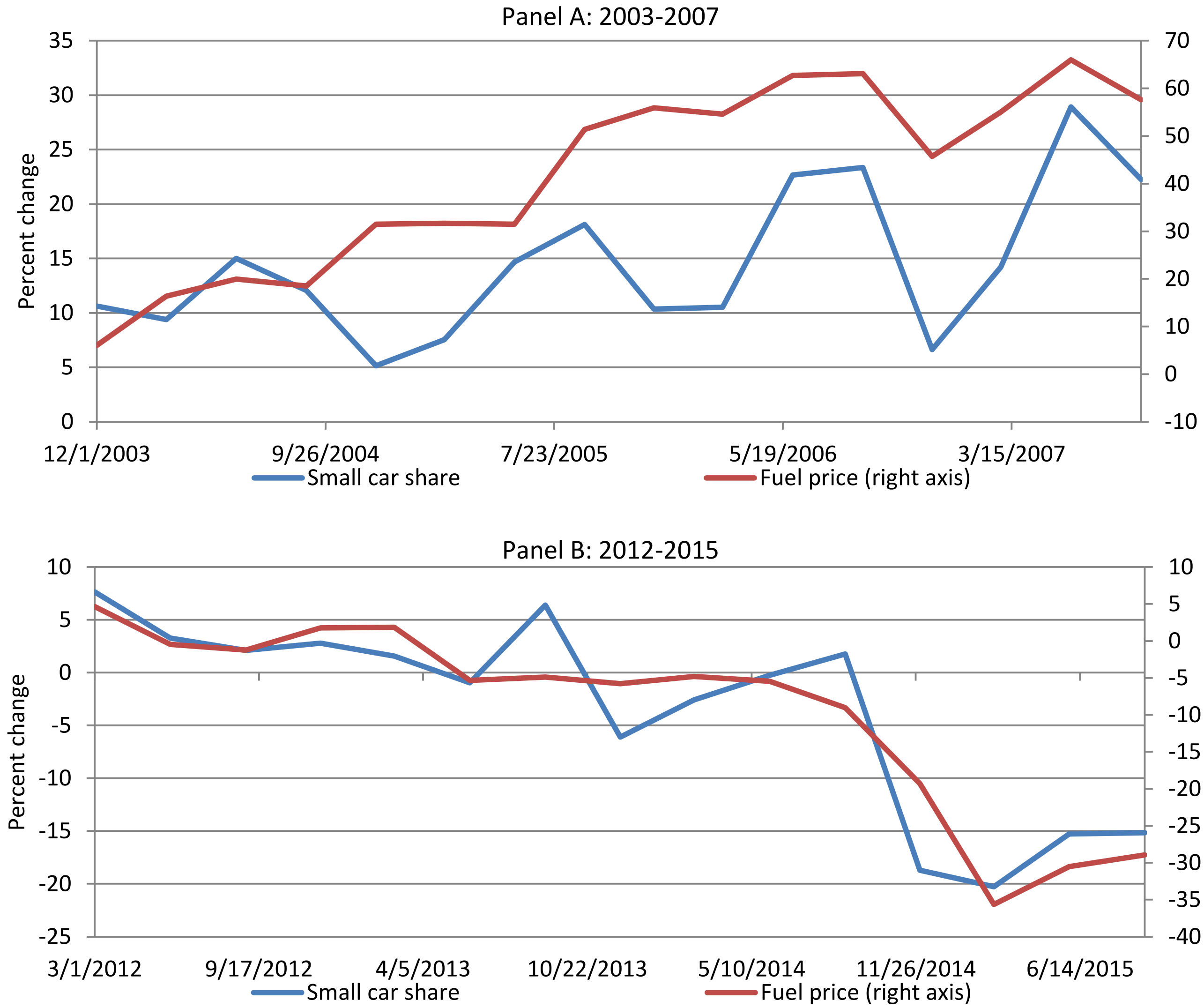
Notes : The figure is constructed similarly to Figure 4, except using data from model year 2015 rather than 2011.

Figure 6. Market Share of Cars and Fuel Prices



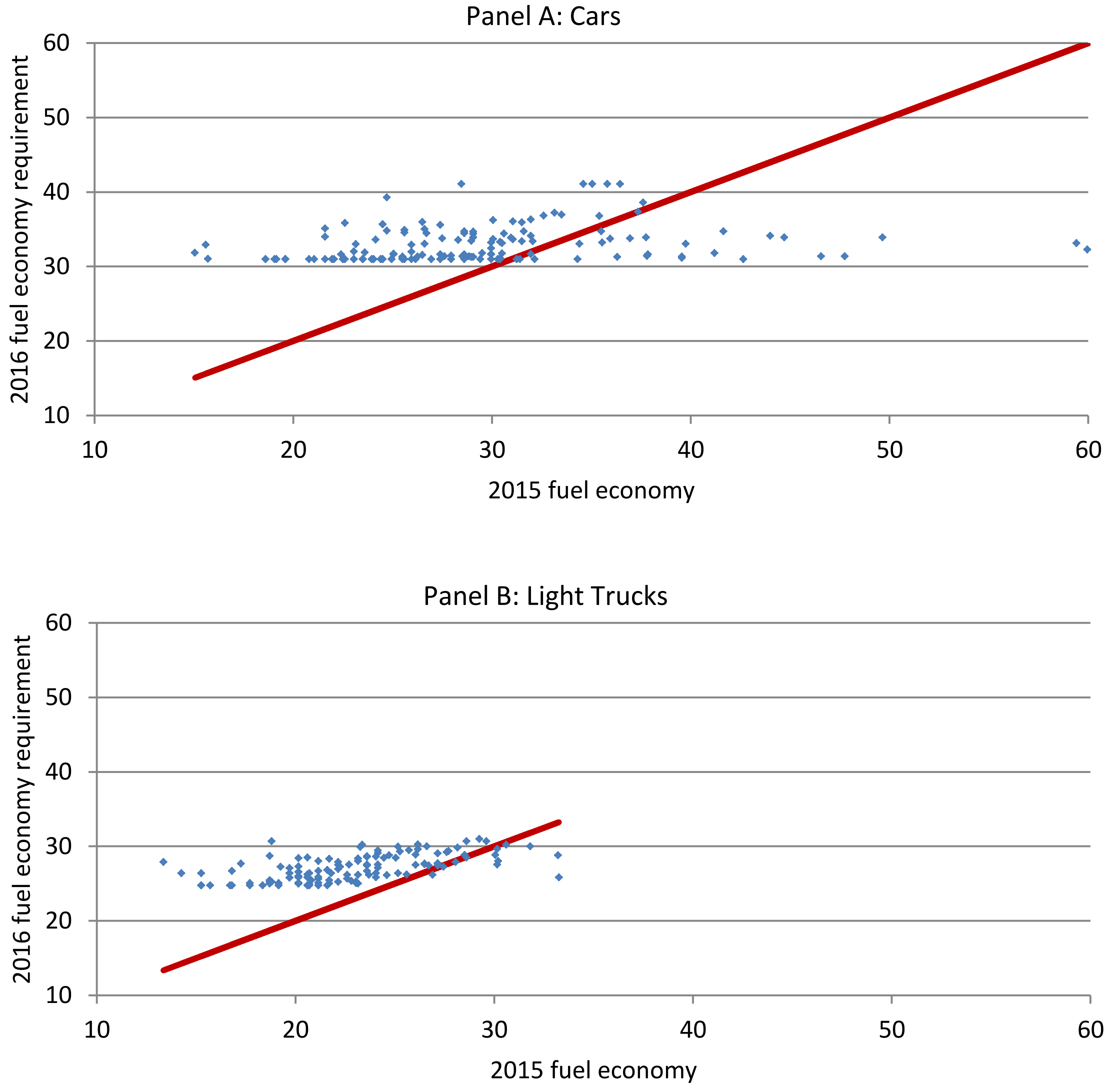
Notes : The quarterly average share of cars in total sales and quarterly sales-weighted average fuel price are calculated for model years 2003-2007 (Panel A) and 2012-2015 (Panel B). The figure plots the percent change of the car share and fuel price since the first quarter of model year 2003 (Panel A) and model year 2012 (Panel B).

Figure 7. Market Share of Small Cars and Fuel Prices



Notes : A small car is defined as having a footprint below the 33rd percentile of the footprint distribution for the corresponding model year. The figure is constructed similarly to Figure 6 except using the share of small car sales in total car sales rather than the car share of sales in total sales.

Figure 8. 2016 Fuel Economy Requirement vs. 2015 Fuel Economy



Notes : Observations are by model and power type for model year 2015. The blue dots plot the 2016 fuel economy requirement against the 2015 fuel economy for cars (Panel A) and light trucks (Panel B). The red line indicates the 45 degree line.

Table 1. Vehicle Summary Statistics by Time Period

	1996-2002	2003-2007	2008-2015
Number of monthly observations	200.7	237.5	278.2
	(9.2)	(11.0)	(15.6)
Sales	6624	5708	3988
	(8813)	(8100)	(6138)
Fuel economy	23.5	23.3	24.7
	(5.1)	(5.7)	(7.0)
Horsepower	165.9	194.1	208.1
	(44.0)	(53.4)	(66.0)
Footprint (sq ft)	54.7	57.2	57.0
	(7.3)	(8.1)	(7.7)
Weight (lbs)	3377	3701	3700
	(670)	(799)	(800)
Light truck market share	0.48	0.54	0.50
Fuel price (8/2015 = 1)	0.69	1.00	1.28
	(0.08)	(0.17)	(0.19)

Notes : The table reports means with standard deviations in parentheses. Each column includes observations from the indicated range of model years. Except for the rows reporting monthly observations and sales, means and standard deviations are sales-weighted. Each vehicle's real fuel price is normalized to equal 1 in August 2015 before computing the mean.

Table 2. Effects of Fuel Prices on Fuel Economy, Footprint, and Standard

	(1)	(2)	(3)
Dependent variable is	Log fuel economy	Log footprint	Log 2016 requirement
		Panel A: Levels	
Log fuel price	0.024 (0.012)	-0.013 (0.006)	0.019 (0.005)
Number of observations	239	239	239
R squared	0.93	0.92	0.95
		Panel B: First Differences	
Log fuel price	0.049 (0.012)	-0.021 (0.008)	0.024 (0.006)
Number of observations	238	238	238
R squared	0.30	0.31	0.42

Notes : The table reports regression coefficients with standard errors in parentheses, robust to heteroskedasticity. Observations are by year and month from October 1995 through August 2015. The column headings indicate the dependent variable. Log fuel economy is the log of the sales-weighted fuel economy, and similarly for log footprint. The log 2016 standard is the log of the sales-weighted average of the fuel economy requirement the vehicle would be subject to in 2016, which is calculated using the vehicle's footprint. Log fuel price is the log of the sales-weighted average of the vehicle's fuel price, which is calculated using the vehicle's power source.

Table 3. Effects of Cost per Mile on Sales

	(1)	(2)	(3)	(4)
		Panel A: Regression results		
Cost per mile	-7.68 (1.61)	-7.49 (0.98)		
Cost per mile X 1996 - 2002			-11.95 (6.20)	2.33 (3.68)
Cost per mile X 2003 - 2007			-19.02 (2.95)	-12.90 (2.02)
Cost per mile X 2008 - 2015			-5.17 (1.87)	-6.83 (1.16)
Number of observations	57,536	52,667	57,536	52,667
R squared	0.95	0.16	0.95	0.16
First differences?	No	Yes	No	Yes
		Panel B: Effects of 2014 fuel prices on 2015 outcomes		
Average fuel economy	0.37	0.37	0.25	0.33
2016 fuel economy requirement	0.14	0.14	0.09	0.13
Percentage of fuel consumption gains eroded	4.20	4.12	2.84	3.75

Notes : Panel A reports regression coefficients with standard errors in parentheses, clustered by model and model year. The dependent variable is log sales by model and month. Cost per mile is the gasoline price divided by fuel economy. Observations are first-differenced in columns 2 and 4. Columns 3 and 4 include interactions of cost per mile with the indicated time periods. Panel B reports the estimated effects of the changes in fuel prices between 2014 and 2015. The first two rows show the changes in the sales-weighted average fuel economy and level of the 2016 fuel economy requirement, if 2015 fuel prices had remained at 2014 levels. Between 2011 and 2014 the average fuel consumption rate decreased 9 percent. The third row reports the percentage of that reduction that is eroded as a result of the lower fuel economy requirement. Columns 3 and 4 use the 2008-2015 coefficient estimate for these calculations.

Table 4. Effects of Price Increases and Decreases on Market Shares

	(1)	(2)	(3)	(4)	(5)
			Panel A: Levels		
Cost per mile	-5.00	-5.18	-5.40	-5.23	-5.10
	(1.91)	(1.88)	(1.86)	(1.91)	(1.88)
Cost per mile X price increase	-0.23				
	(0.17)				
Cost per mile X large price increase		-0.54			
		(0.32)			
Cost per mile X large price decrease			0.85		
			(0.29)		
Cost per mile X 3-month increase				0.13	
				(0.30)	
Cost per mile X 3-month decrease					0.58
					(0.34)
R squared	0.95	0.95	0.95	0.95	0.95
			Panel B: First Differences		
Cost per mile	-5.33	-5.71	-7.70	-6.07	-6.97
	(1.35)	(1.26)	(1.80)	(1.21)	(1.27)
Cost per mile X price increase	-3.83				
	(2.07)				
Cost per mile X large price increase		-4.69			
		(2.64)			
Cost per mile X large price decrease			1.67		
			(2.17)		
Cost per mile X 3-month increase				-8.70	
				(3.66)	
Cost per mile X 3-month decrease					0.64
					(3.02)
R squared	0.16	0.16	0.16	0.16	0.16

Notes : The table reports regression coefficients with standard errors in parentheses, clustered by model and model year. The sample includes model years 2008-2015. Panel A reports levels regressions and Panel B reports first-differenced regressions. The number of observations is 26,428 in Panel A and 24,171 in Panel B. Price increase is a dummy variable equal to one if the seasonally adjusted gasoline price increased between the previous and current months. The price increase is interacted with cost per mile in column 1. Large price increase is a dummy variable equal to one if the price increase is larger than the 75th percentile of monthly price changes over 1996-2015. Large price decrease is defined analogously, and the large price increase or decrease variable is interacted with cost per mile in columns 2 and 3. The 3-month increase variable is an indicator equal to one if the gasoline price increased for three consecutive months. The variable is interacted with cost per mile in column 4, and analogously for a 3-month decrease indicator variable in column 5.

Table 5. Effects of High Prices on Market Shares

	(1)	(2)	(3)	(4)	(5)	(6)
				Panel A: Levels		
Cost per mile	-8.50	-17.08	-9.50	-8.60	-17.20	-5.82
	(2.32)	(3.94)	(2.85)	(1.86)	(3.13)	(2.26)
Cost per mile X price > $2.50	0.45	-0.54	2.67			
	(0.47)	(0.52)	(0.80)			
Cost per mile X consec. months > $2.50				0.019	-0.220	0.011
				(0.018)	(0.097)	(0.019)
Number of observations	57,536	14,249	26,428	57,536	14,249	26,428
R squared	0.95	0.94	0.95	0.95	0.94	0.95
				Panel B: First Differences		
Cost per mile	-10.07	-11.00	-14.84	-9.30	-12.93	-9.11
	(1.29)	(2.35)	(1.85)	(1.17)	(2.05)	(1.49)
Cost per mile X price > $2.50	1.10	-0.42	4.10			
	(0.32)	(0.28)	(0.63)			
Cost per mile X consec. months > $2.50				0.038	0.012	0.037
				(0.012)	(0.182)	(0.013)
Number of observations	52,667	13,053	24,171	52,667	13,053	24,171
R squared	0.18	0.19	0.17	0.16	0.19	0.17

Notes : The table reports regression coefficients with standard errors in parentheses, clustered by model and model year. The sample includes model years 1996 - 2015 in columns 1 and 4, 2003-2007 in columns 2 and 5, and 2008-2015 in columns 3 and 6. Panel A reports levels regressions and Panel B reports first-differenced regressions. Cost per mile X gas price > $2.50 is the interaction of cost per mile with an indicator variable equal to one if the monthly gasoline price is above $2.50 per gallon. Consecutive months is the number of months that the gasoline price has been above $2.50 per gallon. The variable is interacted with cost per mile in columns 4-6.

Table 6. Effects of Cost per Mile by Distance from Fuel Economy Standard

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Cost per mile	-4.52 (3.16)	-5.04 (2.04)						
Cost per mile X make distance	-27.01 (72.54)	-70.41 (50.26)					-15.44 (72.28)	-70.55 (50.18)
Cost per mile X lowest distance group			-17.58 (3.23)	-13.24 (2.47)	-4.71 (1.96)	-7.22 (1.32)	-4.34 (3.17)	-5.47 (2.13)
Cost per mile X distance group 2			-17.32 (3.74)	-15.03 (2.99)	-4.29 (2.11)	-6.67 (1.54)	-3.93 (3.24)	-5.02 (2.22)
Cost per mile X distance group 3			-15.64 (3.88)	-13.46 (3.00)	-4.51 (2.29)	-7.73 (1.65)	-4.15 (3.35)	-6.05 (2.33)
Cost per mile X highest distance group			-15.33 (4.23)	-13.96 (3.65)	-2.92 (2.57)	-7.96 (1.95)	-2.57 (3.55)	-6.30 (2.59)
Number of	14,249	13,053	26,428	24,171	26,428	24,171	26,428	24,171
R squared	0.94	0.19	0.95	0.16	0.95	0.16	0.95	0.16
First differences?	No	Yes	No	Yes	No	Yes	No	Yes
Sample includes	2008-2015	2008-2015	2003-2007	2003-2007	2008-2015	2008-2015	2008-2015	2008-2015

Notes : The table reports regression coefficients with standard errors in parentheses, clustered by model and model year. Regressions are the same as in Table 3 except that cost per mile is interacted with two proxides for the stringency of fuel economy standards. Columns 1, 2, 7, and 8 include the interaction of cost per mile with the average fuel consumption rate distance by make and class, lagged by one model year. The fuel consumption rate distance is the difference between the vehicle's fuel consumption rate and the reciprocal of its fuel economy standard. Fuel consumption rate distance groups are defined so that each group has approximately the same total sales in each model year. In column 3-8 cost per mile is interacted with indicator variables for the four distance groups. Columns 3 and 4 include observations from 2003-2007 and all other columns include 2008-2015. Columns 1, 3, 5, and 7 are estimated in levels and columns 2, 4, 6, and 8 are estimated in first differences.

Table 7. Additional Specifications

	(1)	(2)	(3)	(4)	(5)
			Panel A: Levels		
Cost per mile	-10.23	-6.35	-3.26	-5.28	-5.15
	(2.12)	(2.32)	(2.49)	(1.87)	(1.87)
1-month lag cost per mile	4.14	-6.12			
	(1.54)	(2.30)			
2-month lag cost per mile		7.47			
		(1.66)			
Number of observations	24,171	21,915	19,949	26,428	26,428
R squared	0.96	0.96	0.96	0.95	0.95
			Panel B: First Differences		
Cost per mile	-6.93	-6.44	-6.09	-6.68	-6.83
	(1.51)	(1.61)	(1.86)	(1.16)	(1.16)
1-month lag cost per mile	-1.39	-1.59			
	(1.24)	(1.74)			
2-month lag cost per mile		1.55			
		(1.37)			
Number of observations	21,915	19,659	18,237	24,171	24,171
R squared	0.19	0.18	0.16	0.17	0.16

Notes : The table reports regression coefficients with standard errors in parentheses, clustered by model and model year. The sample includes model years 2008-2015, except for column 3, which omits model years 2008 and 2009. Panel A reports levels regressions and Panel B reports first-differenced regressions. The 1- and 2-month lag cost per mile are the 1- and 2-month lags of cost per mile. Column 4 includes a linear monthly time trend and the interaction of the linear monthly trend with an indicator variable equal to one for light trucks. Column 5 includes interactions of a linear monthly time trend with the manufacturer categories in Figure 3.

Table 8. Effects of Cost per Mile by Fuel Economy Group

	(1)	(2)	(3)	(4)
		Panel A: Regression results		
Cost per mile X lowest mpg group	-6.81	-8.08	-4.72	-7.82
	(1.73)	(4.85)	(1.99)	(5.38)
Cost per mile X mpg group 2	-7.01	-6.17	-5.04	-9.74
	(1.84)	(5.68)	(2.09)	(6.22)
Cost per mile X mpg group 3	-7.28	-3.52	-5.43	-8.19
	(1.93)	(5.75)	(2.23)	(6.33)
Cost per mile X mpg group 4	-5.41	-5.36	-3.82	-12.95
	(2.12)	(6.51)	(2.46)	(7.59)
Cost per mile X highest mpg group	-4.67	4.04	-3.62	-3.89
	(2.35)	(7.52)	(2.75)	(8.69)
Number of observations	57,536	52,667	26,428	24,171
R squared	0.95	0.07	0.95	0.01
First differences?	No	Yes	No	Yes
Sample includes	1996-2015	1996-2015	2008-2015	2008-2015
		Panel B: Effects of 2014 fuel prices on 2015 outcomes		
Average fuel economy	0.40	0.59	0.28	0.50
2016 fuel economy requirement	0.16	0.18	0.11	0.17
Percentage of fuel consumption gains eroded	4.66	5.25	3.34	5.06

Notes : Panel A reports regression coefficients with standard errors in parentheses, clustered by model and model year. Regressions are the same as in Table 3 except the cost per mile is interacted with a set of indicator variables for the vehicle's fuel economy group. Fuel economy groups are defined so that each group has approximately the same total sales in each model year. Panel A reports the coefficients on the interaction terms. Columns 1 and 2 include observations from 1996-2015 and columns 3 and 4 include 2008-2015. Panel B reports the results of a similar set of calculations to those reported in Table 3.

Appendix Table 1. Effects of Cost per Mile by Power Type

	(1)	(2)	(3)	(4)	(5)	(6)
			Panel A: Levels			
Cost per mile	-18.14 (3.12)	-18.55 (3.19)	-18.63 (3.07)	-4.82 (1.95)	-7.34 (1.60)	-3.17 (1.00)
Cost per mile X hybrid	10.43 (5.67)	46.85 (26.92)		2.96 (2.78)	19.90 (10.34)	
Cost per mile X electric				5.28 (12.91)	-33.33 (36.60)	
Number of observations	14,249	14,249	14,074	26,428	26,428	23,005
R squared	0.94	0.94	0.94	0.95	0.96	0.95
			Panel B: First Differences			
Cost per mile	-12.42 (2.05)	-13.14 (2.06)	-13.00 (1.98)	-6.96 (1.24)	-5.78 (1.14)	-2.76 (1.27)
Cost per mile X hybrid	5.49 (5.49)	68.01 (31.42)		-1.06 (2.00)	-8.02 (7.64)	
Cost per mile X electric				-1.78 (13.73)	-50.47 (34.99)	
Number of observations	13,053	13,053	12,893	24,171	24,171	21,051
R squared	0.19	0.20	0.19	0.16	0.19	0.19
Sample includes	2003-2007	2003-2007	2003-2007	2008-2015	2008-2015	2008-2015
Time controls	Year X month	Year X month X power	Year X month	Year X month	Year X month X power	Year X month
Data aggregated across power types?	No	No	Yes	No	No	Yes

Notes : The table reports regression coefficients with standard errors in parentheses, clustered by model and model year. Panel A reports levels regressions and Panel B reports first-differenced regressions. Columns 1-3 include observations from model years 2003-2007 and columns 4-6 include observations from model years 2008-2015. Columns 1, 3, 4, and 6 include year-month interactions and columns 2 and 5 include year-month power type interactions. Observations are aggregated across power type in columns 3 and 6. Hybrid is an indicator variable equal to one if the vehicle has a hybrid power train. Electric is an indicator variable equal to one if the vehicle is a plug-in electric vehicle. The electric indicator variable is interacted with cost per mile in columns4, and 5.