Market Mechanisms and Incentives: Applications to Environmental Policy

A Workshop sponsored by U.S. Environmental Protection Agency’s National Center for Environmental Economics (NCEE) and National Center for Environmental Research (NCER)

Resources for the Future
1616 P Street, NW, Washington, DC 20036
(202) 328-5000

Wednesday, April 29, 2009

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8:30 a.m. – 9:15 a.m. Registration

9:15 a.m. – 9:30 a.m. Introductory Remarks: Julie Hewitt, Chief, Economic and Environmental Assessment Branch, Office of Water

9:30 a.m. – 11:20 a.m. Session I: Fuel Economy and Gasoline Prices
Session Moderator: Cynthia Morgan, EPA, National Center for Environmental Economics

9:30 a.m. – 10:00 a.m. Imperfect Competition, Consumer Behavior, and the Provision of Fuel Efficiency in Vehicles
Carolyn Fischer, Resources for the Future

10:00 a.m. – 10:30 a.m. New Vehicle Characteristics and the Cost of the Corporate Average Fuel Economy Standard
Thomas Klier, Federal Reserve Bank of Chicago, and Joshua Linn, University of Illinois at Chicago

10:30 a.m. – 10:40 a.m. Discussant: Gloria Helfand, University of Michigan, and EPA, Office of Transportation and Air Quality

10:40 a.m. – 10:50 a.m. Discussant: Winston Harrington, Resources for the Future

10:50 a.m. – 11:20 a.m. Questions and Discussion

11:20 a.m. – 12:30 p.m. Lunch (On Your Own)

12:30 p.m. – 1:30 p.m. Panel Discussion: Role of Market Mechanisms and Incentives to Climate Change
Moderator: Dick Morgenstern, Resources for the Future
Panelist: Joe Aldy, Special Assistant to the President for Energy and the Environment
          David McIntosh, Senior Counsel in the Office of Congressional and Intergovernmental Relations
          Brian Murray, Duke University

1:30 p.m. – 1:40 p.m. Break

1:40 p.m. – 3:30 p.m. Session II: Applications of Environmental Trading Programs
Session Moderator: Will Wheeler, EPA, National Center for Environmental Economics

1:40 p.m. – 2:00 p.m. An Experimental Analysis of Compliance in Dynamic Emissions Markets: Theory and Experimental Design
John Stranlund, University of Massachusetts - Amherst, James Murphy, University of Alaska – Anchorage, and John Spraggon, University of Massachusetts - Amherst
2:00 p.m. – 2:30 p.m. Can Markets for Development Rights Improve Land Use and Environmental Outcomes?  
Virginia McConnell, Elena Safirova, Margaret Walls, and Nick Magliocca, Resources for the Future

2:30 p.m. – 2:35 p.m. Discussant: Heather Klemick, EPA, National Center for Environmental Economics

2:35 p.m. – 3:05 p.m. Preliminary Findings and Observations on Ohio’s Great Miami River Water Quality Credit Trading Program  
Richard Woodward, Texas A&M University

3:05 p.m. – 3:10 p.m. Discussant: Hale Thurston, EPA, National Risk Management Research Laboratory

3:10 p.m. – 3:30 p.m. Questions and Discussion

3:30 p.m. – 3:40 p.m. Break

3:40 p.m. – 5:30 p.m. Session III: Winners and Losers in Cap and Trade  
Session Moderator: Charles Griffiths, EPA, National Center for Environmental Economics

3:40 p.m. – 4:10 p.m. Paving the Way for Climate Policy: Compensation for Electricity Consumers and Producers Under a CO₂ Cap and Trade Policy  
Karen Palmer, Dallas Burtraw, and Anthony Paul, Resources for the Future

4:10 p.m. – 4:40 p.m. When Does Cap-and-Trade Increase Regulated Firms’ Profits?  
Dave Evans, EPA, National Center for Environmental Economics; Ian Lange, University of Stirling; and Joshua Linn, University of Illinois at Chicago

4:40 p.m. – 4:50 p.m. Discussant: Ann Wolverton, EPA, National Center for Environmental Economics

4:50 p.m. – 5:00 p.m. Discussant: Terry Dinan, Congressional Budget Office

5:00 p.m. – 5:30 p.m. Questions and Discussion

5:30 p.m. Adjournment
Imperfect Competition, Consumer Behavior, and the Provision of Fuel Efficiency in Light-Duty Vehicles

Carolyn Fischer

Abstract

We explore the role of market power on the cost-effectiveness of policies to address fuel consumption. Market power gives manufacturers an incentive to under- (over-) provide fuel economy in classes whose consumers, on average, value it less (more) than in others. Adding a second market failure in consumer valuation of fuel economy, a policy tradeoff emerges. Minimum standards can address distortions from price discrimination but do not provide broad-based incentives for improving fuel economy like average standards. Increasing fuel prices raises demand for fuel economy but exacerbates undervaluation and incentives for price discrimination. A combination policy may be preferred.
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Introduction

The regulation of fuel economy is one of the primary tools for controlling the emissions of greenhouse gases and other pollutants from passenger vehicles in the U.S., as well as for addressing energy security. Heightened attention to these issues has prompted a broader debate over reforming Corporate Average Fuel Economy (CAFE) standards, the current program that requires automobile manufacturers to meet standards for the sales-weighted average fuel economy of their passenger vehicle fleets. Potential reforms include not only strengthening standards, but also allowing fuel economy credits to be tradable, and adjusting standards according to vehicle characteristics like size.1

This study addresses an issue that has been overlooked in previous studies of CAFE standards and alternatives: that imperfect competition can affect manufacturer incentives to deploy fuel-saving technologies. While it is well known that market power affects price markups, the distributional effects of regulation, and even the fleet mix, its effects on the choice of fuel economy have been ignored. We explore the impact of this particular brand of market failure on the cost-effectiveness of tradable fuel economy standards and other market-based mechanisms to address automotive fuel consumption.

In particular, we investigate the role of market power among automobile manufacturers and of heterogeneity among consumers in their preferences for fuel economy. In this situation, manufacturers have an incentive to choose fuel economy to differentiate their product line,

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1 The latter modification is being implemented for light trucks. Fischer and Portney (2004) discuss the case for making CAFE credits tradable.
segment consumers, and thus obtain higher prices for their fleet of vehicles. Meanwhile, CAFE standards impose certain constraints on these choices, by requiring manufacturers to meet an average rate of fuel consumption. An important question for evaluating reforms to CAFE standards is how do they interact with incentives for price-discrimination that may distort the provision of fuel economy in passenger vehicles?

Common sense dictates that consumers of different car classes are likely to have different preferences for fuel economy, in part because those preferences help determine the class they choose. For example, people more concerned about fuel economy—whether because they drive more, understand the costs better, or care about the environment—would be less likely to choose a large car. They may also be more likely to forego purchasing a car.

Empirical studies support this claim. Goldberg (1995), in her estimation of vehicle demand, finds that while consumers of large and small cars are similarly sensitive to prices, consumer demand for small cars is much more elastic with respect to fuel costs than is demand for large cars (Table 1). Luxury car demand is less sensitive to prices and basically insensitive to fuel costs.

*Table 1: Results from Goldberg (1995) Log-Likelihood Demand Estimation*

<table>
<thead>
<tr>
<th>Model Choice: Variable</th>
<th>Small Cars</th>
<th>Big Cars</th>
<th>Luxury and Sports Cars</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>price if purchased</td>
<td>-4.747 (0.862)</td>
<td>-4.4 (0.602)</td>
<td>-1.223 (0.174)</td>
</tr>
<tr>
<td>model before and</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>income &lt;= $75000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>price if purchased</td>
<td>-4.501 (0.356)</td>
<td>-3.745 (0.332)</td>
<td></td>
</tr>
<tr>
<td>model before and</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>income &gt; $75000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>price if first-time</td>
<td>-2.927 (0.328)</td>
<td>-3.076 (0.649)</td>
<td>-0.517 (0.220)</td>
</tr>
<tr>
<td>buyer and income &lt;=</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$75000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>price if first-time</td>
<td>-2.755 (1.277)</td>
<td>-2.171 (0.396)</td>
<td></td>
</tr>
<tr>
<td>buyer and income &gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$75000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel costs</td>
<td>-7.143 (0.740)</td>
<td>-1.381 (0.744)</td>
<td>0.231 (0.931)</td>
</tr>
</tbody>
</table>

Similarly, Berry et al. (1995) find that the elasticity of demand with respect to miles per dollar “declines almost monotonically” with the car’s miles per dollar rating. They also
conclude that luxury vehicle buyers are unconcerned with fuel economy, while purchasers of high-mileage cars are quite sensitive to it.

Using survey methodology, Kurani and Turrentine (2004) dispute the notion that consumers follow the rational economic framework for computing fuel consumption costs and weighing fuel economy tradeoffs. Still, if one accepts the idea that consumers behave as if they are seeking a certain payback period, “then averages such as the ‘three-year’ figure that Greene (2002) provides by example are of little interest. Almost every study conducted of consumer payback periods related to energy conservation shows a wide variety of (generally implied) discount rates. This suggests the existence of a market that can be segmented according to how long people are willing to be paid back.”

At the same time, there is certainly empirical support for the presence of market power in the automobile industry: the largest four firms account for 75.5% of the value of shipments in the automobile market and 95.7% of the light duty and utility vehicle market, and the Herfindahl Hirschman Index (HHI) for light vehicles overall is 2600 (2002 Economic Census), where above 1800 is the Justice Departments definition of a “highly concentrated” industry.

The accompanying table gives the market shares of light duty vehicle sales, according to NHTSA, for model year 2004, and those shares are significant for the top five. Furthermore, empirical evidence of significant brand loyalty (Train and Winston, *International Economic Review*, forthcoming) may also serve to reinforce the idea that auto manufacturers will recognize demand interactions across models within their fleet (in other words, that the fuel economy of one model is likely to affect demand for other models in the fleet as well). Thus, the conditions are ripe for market power to play a role in determining vehicle quality, including fuel economy.

However, modelers of automobile markets and their regulation have largely ignored the effects of consumer heterogeneity on the strategy of vehicle manufacturers for providing fuel

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Market Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Motors</td>
<td>26%</td>
</tr>
<tr>
<td>Daimler Chrysler</td>
<td>20%</td>
</tr>
<tr>
<td>Ford</td>
<td>18%</td>
</tr>
<tr>
<td>Toyota</td>
<td>13%</td>
</tr>
<tr>
<td>Honda</td>
<td>8%</td>
</tr>
<tr>
<td>Other</td>
<td>16%</td>
</tr>
</tbody>
</table>

2 Kurani and Turrentine (2004), p. III.
economy. A variety of assumptions have enabled researchers to avoid this question. Many studies that allow for imperfect competition among vehicle manufacturers focus on responses in fleet composition, assuming that fuel economy and marginal production costs for each vehicle model are exogenously determined (Jacobsen 2008; Bento et al. 200?(; Berry et al. 1995; Goldberg 1995, 1998; Kwoka 1983; Petrin 2002). While this assumption is useful for modeling short-run responses to policy or gas price changes, these studies cannot incorporate the longer-run response of changing the fuel consumption characteristics of the vehicle.

Other modelers have allowed manufacturers to choose fuel economy, but they have avoided the strategic problem by assuming perfect competition or by aggregating the market (e.g., Fischer et al. 2005, Kleit 2004, Greene et al. 2005). Similarly, Rubin et al. (2006) abstract from imperfect competition in the product market, while they do evaluate the impact of market power in the market for tradable fuel economy credits. Austin and Dinan (2005) allow imperfectly competitive firms to choose both price and fuel consumption rates for their vehicle models; however, they simplify the problem by assuming that consumers respond to average fuel costs in the same way as they respond to price changes. By this assumption, any fuel economy change then changes the fully-loaded vehicle price (ownership and operating costs) the same amount for all consumers, in which case manipulating fuel economy is no more effective at segmenting consumers than changing the retail price. However, that individual consumers would base their decisions on average consumer behavior is a strong assumption.

Given the degree of concentration among auto manufacturers and the wide range of consumer traits, none of these assumptions is satisfying. We show that when we incorporate consumer heterogeneity into a model of Bertrand price and quality competition, the results are very similar to those in the classic price-discrimination framework (e.g. Fischer 2005, Plourde and Bardis 1999). In this situation, fuel economy will tend to be over-provided in classes whose consumers value it more than others, and underprovided in classes whose consumers value it less than in others. In this manner, fuel economy represents a way to solidify market segmentation; by offering less fuel economy to consumers of large cars, for example, they can charge higher prices to small-car consumers, without worrying they will switch classes. Similarly, they can charge higher prices for large cars when they are charging more for highly efficient small cars than the large-car buyers are willing to pay. As a result, imperfect competition in the product
market creates a market failure in the provision of fuel economy. Overlooking this market failure leaves out an important motivation for fuel economy regulation and will bias estimates of policy cost-effectiveness. On the other hand, as Fischer (2005) shows, average fuel economy regulation is not necessarily the best response to the distortions caused by price discrimination. We will thus consider modifications to tradable CAFE standards that can improve welfare.

This study extends important theoretical underpinnings for improving models of fuel economy policy and for conducting future empirical estimates of consumer and market behavior. These issues are critical for understanding the cost-effectiveness of policies like CAFE and whether they can enhance welfare as well as fuel economy. We complement the analytical work with numerical simulations to evaluate the potential magnitude of the problem. The goal is to inform policymakers about the extent to which fuel economy policy needs to keep an eye on market power issues, and the corresponding sensitivity analysis will also help identify key parameters for further empirical research.

Model

**Theory of Producer Behavior**

Consider a representative firm in our automobile manufacturing sector. For each vehicle class, the manufacturer chooses a retail price $P_i$, and a fuel consumption rate $\phi_i$. We specify a model with Bertrand competition and product differentiation that can easily be extended to any number of manufacturers. A given manufacturer will care about how its choices will affect its entire product line, taking the choices made by other manufacturers as given.

The costs of manufacturing a vehicle of class $i$ are $C_i(\phi_i)$, a function that is decreasing and convex in fuel consumption ($\frac{\partial C_i}{\partial \phi_i} < 0$ and $\frac{\partial^2 C_i}{\partial \phi_i^2} > 0$). Consumer demand for class $i$ is a function of the vector of prices and fuel consumption rates for all vehicles ($q_i(P, \phi)$). Demand in class $i$ is decreasing in its own price and fuel consumption rate, and weakly increasing in those of other classes. Profits $V$ for the representative manufacturer are the retail price less production costs, multiplied by the output of each model class:
\[ V(P, \varphi) = \sum_i (P_i - C_i(\phi_i))q_i(P, \varphi) \]  

(1)

Price. Maximizing profits with respect to the price of each vehicle class \( i \) leads to the following first-order condition:

\[ \frac{\partial V(P, \varphi)}{\partial P_i} = q_i + \sum_j \pi_j \frac{\partial q_j}{\partial P_i} = 0 \]  

(2)

where \( \pi_j = P_j - C_j(\phi_j) \) is the own marginal profit (or total markup) for vehicle type \( j \). Let \( \eta_{ji} = \frac{\partial q_j}{\partial P_i} \frac{P_j}{q_j} \) be the cross-price elasticity of demand for vehicle class \( j \) with respect to a change in the price of \( i \). Then we can rewrite the pricing condition as

\[ P_i = \sum_j \pi_j(-\eta_{ji}) \frac{q_j}{q_i} \]  

(3)

Rearranging, we can express the price as the sum of the vehicle’s own costs, with a markup according to its own-price elasticity, and the cross-price responses, weighted by the marginal profits of the other vehicles in the manufacturer’s fleet:

\[ P_i = C_i(\phi_i) \frac{\eta_{ii}}{\eta_{ii} + 1} + \sum_{j \neq i} \pi_j \frac{-\eta_{ji}}{(\eta_{ii} + 1)} \frac{q_j}{q_i} \]  

(4)

From (4) we see that a change in one model’s costs, all else equal, causes a proportional increase in the price, with that ratio depending on the own-price elasticity of demand:

\[ \Delta P_i = \frac{\eta_{ii}}{\eta_{ii} + 1} \Delta C_i(\phi_i). \]  

Note that this result implies that more than 100% of the marginal cost increases are passed through to consumers. Equilibrium price changes, however, will reflect both cost changes and the demand interactions for all the vehicle classes. Thus, the effective pass-through rates for different model classes could be more or less than 100% in equilibrium. In the perfectly competitive case, as \( \eta_{ii} \to -\infty \) the firm becomes a price taker and we get a 100% pass-
through of cost changes into retail prices. However, most empirical studies have found positive markups, validating models of oligopolistic competition.  

Fuel Consumption Rate. Next, we consider the incentives with respect to fuel economy. The first-order conditions are

$$\frac{\partial V(P, \phi)}{\partial \phi_i} = -\frac{\partial C_i(\phi)}{\partial \phi_i} q_i + \sum_j \pi_j \frac{\partial q_j}{\partial \phi_i} = 0$$

(5)

Using the first-order condition with respect to the retail price, this equation simplifies to

$$-\frac{\partial C_i(\phi)}{\partial \phi_i} = \sum_j \pi_j \frac{\partial q_j}{\partial P_i}$$

(6)

Let $g\bar{\rho}_i$ be the average willingness to pay for decreases in the fuel consumption rate among consumers of car class $i$ (the fuel price $g$ multiplied by a factor reflecting annual VMT, discounting, and preferences). Efficiency, at least in allocating fuel economy, would require that

$$-\frac{\partial C_i(\phi)}{\partial \phi_i} = g\bar{\rho}_i,$$

meaning the per-vehicle cost increase equals that average willingness to pay for lower fuel consumption.

With Bertrand pricing, this condition holds if

$$\sum_j \pi_j \frac{\partial q_j}{\partial \phi_i} = g\bar{\rho}_i \sum_j \pi_j \frac{\partial q_j}{\partial P_i}.$$

For example, a sufficient situation would be

$$\frac{\partial q_j}{\partial \phi_i} = g\bar{\rho} \frac{\partial q_j}{\partial P_i}$$

for all $j$, that is, if consumers in all classes respond to a fuel consumption change in class $i$ in proportion to the way they respond to a price change in that class, with that proportion being the average willingness to pay among all consumers. This

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3 Bresnahan (1981) and Feenstra and Levinsohn (1995) found markups in the range of 4%-25% for individual models. The NRC study assumed a 40% markup for cost increases, shared across parts and auto manufacturers and retailers. This and subsequent studies used published dealer markups and the estimated ratio of dealer and manufacturer markups from Bresnahan and Reiss (1986). Bento et al. (2008) find markups in the range of 14-46.
situation occurs in Austin and Dinan (2005), since consumers in all classes are assumed to have on average the same sensitivity to fuel consumption rates \((\rho_i = \rho\) for all \(i\)), although there could still be different utilization and internalization rates within classes. The other obvious situation is if \(\pi_j = 0, \forall j \neq i\), as with perfect competition.

The proportionality assumption (the first condition above) has attractive properties for modelers of CAFE policy. Note that if consumers respond to fuel costs in the same way as price changes, the pricing strategy does not directly affect fuel economy choice in the maximization problem (by the Envelope Theorem). In other words, imperfect competition does not create an incentive to over- or underprovide fuel economy. Rather, firms wish to provide all the fuel efficiency demanded, in order to maximize the rents from the price markups.

However, as we have discussed, it seems more reasonable to believe that consumers of different car classes have different preferences for fuel economy, since those preferences help determine the class they choose. Suppose consumers do respond “rationally” to fuel costs in the same way as prices, but they differ in their valuation of the fuel consumption rate. For example, suppose the cost to the average consumer of vehicle type \(j\) for driving vehicle \(i\) would then be \(g\rho_j\phi_i\). In this situation, \[\frac{\partial q_i}{\partial \phi_i} = g\rho_j \frac{\partial q_j}{\partial P_i} \]. Furthermore, \[\frac{\partial q_j}{\partial P_i} = \frac{\eta_j q_j}{P_i} \]. Substituting, we get

\[
-\frac{\partial C_i(\phi_i)}{\partial \phi_i} = g \left( \rho_i + \frac{\sum_j (\rho_i - \rho_j) \pi_j \eta_j q_j}{-\sum_j \pi_j \eta_j q_j} \right)
\]  

(Recall that \(\partial q_j / \partial P_i > 0\) for \(j \neq i\) and that from (2) the denominator is positive if \(q_i > 0\), meaning simply that the own-price effect dominates the cross-price effects.) In other words, fuel economy will tend to be over-provided in classes whose consumers, on average, value it more than in others, and underprovided in classes whose consumers value it less than in others. In this manner, fuel economy represents a way to solidify market segmentation; by offering less fuel economy to consumers of large cars, for example, they can charge higher prices to small-car consumers, without worrying they will switch classes. Similarly, they can charge higher prices
for large cars when they are charging more for highly efficient small cars than the large-car buyers are willing to pay.

This same result can in theory be extended to any vehicle quality. Quality competition can occur over several characteristics, not just one, as long as the valuation of each characteristic varies across product classes. For our purposes, however, we assume that other features are held constant.

*Fuel Economy Regulation and Producer Behavior*

In this section, we consider how different kinds of policy interventions affect the distortions that may arise out of price discrimination incentives. We find that most either do little or exacerbate them, with the potential exception of minimum fuel economy standards.

**Higher Gasoline Prices**

One policy for improving fuel economy is increasing gasoline prices through taxation or other means. The effects of higher gasoline prices on producer incentives are evident in Equation (8): they raise the average consumer willingness to pay for fuel economy, and they also proportionately magnify the strategic incentives for distorting fuel economy provision to facilitate price discrimination.

**CAFE Standards**

The CAFE standards require that each manufacturer’s fleet must meet or surpass a harmonic average for fuel economy, measured in miles per gallon, for all the vehicles of that type. We consider a stylized version of the domestic new vehicle market, in which we initially abstract from the differentiation between cars and light trucks. In this first case, we consider the uniform CAFE standard, as is currently applied to passenger cars. (In essence, this assumption is equivalent to zero cross-price elasticity between cars and trucks, which is obviously strong.) However, in the second case, we consider size-based standards, as are being implemented in the light truck category, or could also reflect the different standards for cars and trucks.

The uniform CAFE standard is equivalent to mandating that the average fuel consumption rate for the fleet be below the corresponding standards, expressed as $\bar{\phi}$. That is, if
\( q_i \) is the sales of vehicles in class \( i \), CAFE standards mandate that for each fleet of autos, 
\[ \sum_i \phi_i q_i \leq \bar{\phi} \sum_i q_i. \]

The manufacturer then maximizes profits, subject to the prevailing fuel economy constraint, defined as an average fuel consumption rate (or a harmonic average of MPG). The Lagrangian is

\[
L = \Pi(P, \varphi) - \lambda \sum_i (\phi_i - \bar{\varphi})q_i(P, \varphi) \tag{8}
\]

Maximizing profits with respect to the price of each vehicle class \( i \) leads to a similar first-order condition as in (3), but the full marginal profit for vehicle type \( j \) includes the shadow value of the extent to which its fuel consumption rate is above or below the standard. (Furthermore, it is possible that marginal profits excluding the shadow value can now be negative.)

\[
P_i = \sum_j \left( \pi_j - \lambda(\phi_j - \bar{\varphi}) \right) (-\eta_{ji}) \frac{q_j}{q_i} \tag{9}
\]

Let \( \hat{\pi}_j = P_j - C_j(\phi_j) - \lambda(\phi_j - \bar{\varphi}) \). Rearranging, as in Equation (4), we can express the price as the sum of the vehicles own costs, including the implicit net tax or subsidy from the fuel consumption standard, with a markup according to its own-price elasticity, and the cross-price responses, weighted by the marginal profits of the other vehicles in the manufacturer’s fleet:

\[
P_i = \left( C_i(\phi_i) + \lambda(\phi_i - \bar{\varphi}) \right) \frac{\eta_{ii}}{\eta_{ii} + 1} + \sum_{j \neq i} \hat{\pi}_i \frac{-\eta_{ji}}{\eta_{ii} + 1} \frac{q_j}{q_i} \tag{10}
\]

Here we see again that the markup ratio depends on the own-price elasticity of demand, but the basis for cost changes also includes the implicit net tax/subsidy.

The first-order conditions with respect to fuel economy are

\[4\] Although paying a fine is an alternative, we assume that all firms choose to meet the standard, as has been the case. Manufacturers must pay a penalty of $55 per vehicle for every 1 mpg that their fleet average falls below the relevant standard. Vehicles weighing more than 8,500 pounds (such as the Hummer H2 and Ford Excursion) are exempt from CAFE.
\[
\frac{\partial L(P, \phi)}{\partial \phi_i} = \left( -\frac{\partial C_i(\phi_i)}{\partial \phi_i} - \lambda \right) q_i + \sum_j \hat{\pi}_j \frac{\partial q_j}{\partial \phi_i} = 0
\]

(11)

Using the first-order condition with respect to the retail price, this equation simplifies to

\[
-\frac{\partial C_i(\phi_i)}{\partial \phi_i} = \frac{\sum_j \hat{\pi}_j \frac{\partial q_j}{\partial \phi_i}}{\sum_j \frac{\partial q_j}{\partial P_i}} + \lambda
\]

(12)

Thus, the CAFE constraint shifts up the marginal benefit from decreasing the fuel consumption rate by the same amount for all vehicles in the regulatory category, without directly changing the strategic incentives for price discrimination. However, it does have indirect effects on these strategic incentives.

Assuming again that \( \frac{\partial q_j}{\partial \phi_i} = g \bar{\rho}_j \frac{\partial q_j}{\partial P_i} \) and substituting, we see that CAFE standards change the effective marginal profits and thereby the relative weights on the induced demand changes for other vehicles in the fleet:

\[
-\frac{\partial C_i(\phi_i)}{\partial \phi_i} = g \left( \bar{\rho}_i + \sum_j \left( \bar{\rho}_i - \bar{\rho}_j \right) \left( \pi_j - \lambda (\phi_j - \bar{\phi}) \right) \eta_j q_j \right) + \lambda
\]

(13)

In the absence of CAFE, vehicles with higher-than-average consumer willingness to pay for fuel economy have lower-than-average fuel consumption rates, and vice-versa. With CAFE, marginal profits are relatively higher for vehicles with lower-than-average fuel consumption rates. This creates countervailing effects for some vehicle types. In the numerator, larger differences in willingness to pay are correlated with larger differences in fuel economy component effective marginal profits, which tends to magnify the strategic effects. On the other hand, for fuel efficient cars, larger marginal profits also raise the denominator, which is dominated by the own-price effects, thereby dampening this term. For fuel inefficient cars, however, the reduction in marginal effective profits in the denominator magnify the strategic incentives to underprovide fuel economy in larger vehicles.
Size-Based Standards

With size-based standards, CAFE standards are modified such that each manufacturer’s fleet must meet or surpass a harmonic average for fuel economy that depends on the size distribution of its fleet. This method is currently being implemented for light trucks and may be extended to cars. Formally, if \( q_i \) is the sales of vehicles in class \( i \), size-based standards mandate that for each fleet of vehicles, \( \sum_i \phi_i q_i \leq \sum_i \phi_i q_i \). Sized-based standards can improve overall cost-effectiveness over uniform standards if manufacturers are sufficiently heterogeneous and cannot trade credits, as the reduction targets can be better tailored to costs (Elmer and Fischer, 2009). With that rationale in mind, it is useful to consider the case in which these standards better approximate desired fuel economy than the uniform standard for all classes \( |\phi_j - \bar{\phi}_j| < |\phi_j - \bar{\phi}| \), \( \forall j \). The new Lagrangian for the manufacturer is

\[
L = \Pi(P, \phi) - \lambda \sum_i (\phi_i - \bar{\phi}) q_i (P, \phi)
\]

(14)

The (rearranged) first-order conditions are modified from those of the uniform standards to reflect the different allocations of fuel economy credits:

\[
P_i = \left( C_i(\phi_i) + \lambda (\phi_i - \bar{\phi}_i) \right) - \frac{\eta_i}{(\eta_i + 1)} + \sum_{j \neq i} \left( \lambda - \frac{\eta_{ji}}{(\eta_i + 1)} \right) q_j
\]

where \( \hat{\pi}_i = P_j - C_j(\phi_j) - \lambda (\phi_j - \bar{\phi}_j) \). The main difference from the uniform standards is that the deviation in fuel consumption rates from the standard, and thereby the influence of the standard on marginal costs and profits, is mitigated. Of course, the shadow value of fuel economy is also affected by the change in the stringency of the effective standard; for manufacturers specializing more in larger vehicles, this shadow value tends to fall, while for manufacturers of smaller vehicles, the standard tends to become more stringent.

Similarly, in the choice of fuel economy, the first-order conditions are similar to (12), but modified by the change in the distribution of marginal profits. We do assume here that changing size is not an available means for improving fuel economy. See Elmer and Fischer (2009) for the influence of market power on the distortionary effects of weight-based standards. With the same
assumptions and substitutions as before, the first-order condition for fuel economy can be written as

$$-\frac{\partial C_i(\phi_i)}{\partial \phi_i} = g \left[ \sum_j (\bar{\rho}_j - \bar{\rho}_j) \left( \pi_j - \lambda(\phi_j - \bar{\phi}_j) \right) \eta_j q_j \right] + \lambda$$

(16)

In general, size-based standards tend to reduce the change in fully loaded marginal profits relative to uniform standards. This is especially true for large-vehicle manufacturers, who also see the shadow value of fuel economy fall, relative to uniform standards. In the extreme case in which size-based standards accurately reflect the equilibrium fuel economy by class for the manufacturer (so $\bar{\phi}_j = \phi_j$), this condition reduces to that in the absence of regulation, just shifted up by the shadow value of fuel economy. In other words, size-based standards have little effects on the strategic incentives to distort fuel economy provision across vehicle types.

**Minimum Standards**

An alternative standard to CAFE standards would be minimum fuel economy standards. Such standards are used in China, for example, which imposed fuel consumption limits on light-duty passenger cars based on the weights of the vehicles, beginning in 2005.\(^5\)

Under this fuel economy constraint, the Lagrangian for the manufacturer is

$$L = \Pi(P, \varphi) - \sum_i \lambda_i (\phi_i - \bar{\phi}_i) q_i$$

(17)

such that $\lambda_i (\phi_i - \bar{\phi}_i) = 0$ for all $i$. (By multiplying the constraint by the quantity of vehicle sales, we are effectively scaling the shadow value, for consistency with the previous analysis.)

Maximizing profits with respect to the price of each vehicle class $i$ leads to the same first-order condition as in Equations (3) and (4), with the constraint not directly affecting marginal

\(^5\)“Limits of Fuel Consumption for Passenger Cars” was jointly issued by the State Administration of Quality Supervision, Inspection and Quarantine and the Standardization Administration in 2004.
profits: \( \pi_j = P_j - C_j(\phi_j) \), since \( \lambda_i(\phi_j - \bar{\phi}) = 0 \). In other words, this regulation does not create an incentive for fleet-mix shifting via pricing (other than by changes in actual costs).

The first-order conditions with respect to fuel economy look identical to those in Equation (11); the difference here is that the shadow value varies by each class, as opposed to just across cars and trucks. From (12), then, we see that the minimum fuel economy standard shifts up the marginal benefit from decreasing the fuel consumption rate by different amounts for all classes, but only when it is binding.

\[
-\frac{\partial C_i(\phi_i)}{\partial \phi_i} = g \left( \frac{\sum_j (\bar{\rho}_i - \bar{\rho}_j)(\pi_j)\eta_i q_j}{\sum_j (\pi_j)\eta_i q_j} \right) + \lambda_i \tag{18}
\]

In this way, minimum standards can potentially counteract strategic incentives to underprovide fuel economy if they are binding for those market segments. However, they cannot directly address overprovision.

**A Simple Application**

Much of the intuition can be illustrated by considering a manufacturer with two types of cars: large, relatively fuel inefficient cars (\( L \)) and small, relatively fuel efficient cars (\( S \)). Let the \( q \)'s represent fleet shares, such that \( q_L = 1 - q_S \). We will express markups \( m \) as a share of the price, so \( \pi_i = m_i P_i \), and let \( B = P_L / P_S \) be the ratio of large car prices to small car prices. The following simplifications also allow us to represent the willingness to pay for fuel economy and fuel consumption rates as a function of the averages and differences:

\[
\rho_S = \bar{\rho} + \Delta_\rho, \quad \rho_L = \left( \bar{\rho}(1-q_S) - q_S \Delta_\rho \right) / q_L \\
\phi_S = \bar{\phi} - \Delta_\phi, \quad \phi_L = \left( \bar{\phi}(1-q_S) - q_S \Delta_\phi \right) / q_L
\]

Let us focus on the strategic incentives to manipulate fuel economy, or the fuel economy premium (“FE Premium”). Our measure will be difference between the marginal reduction benefits (MRB) to the manufacturer for providing fuel economy—the right hand side of the first-
order conditions for $\phi_i$—from the average consumer willingness to pay. In the absence of regulation (“NR”), this simplifies to

$$MRB_{L}^{NR} - g\bar{\rho}_L = -\frac{gm_s\eta_{sl}q_s\Delta_p}{\chi_L},$$

$$MRB_{S}^{NR} - g\bar{\rho}_S = \frac{gBm_l\eta_{ls}\Delta_p}{\chi_S},$$

where $\chi_L = (-\eta_{ls}Bm_l(1-q_S) - m_s\eta_{sl}q_s)(1-q_S)$ and $\chi_S = (-\eta_{ls}m_sq_S - Bm_l\eta_{ls}(1-q_S))$.

The other main policy of interest is the uniform CAFE standard (“U”), and how it might differ from incentives without regulation. Here,

$$MRB_{L}^{U} - MRB_{L}^{NR} = \lambda - \frac{\lambda}{P_S}\left(q_s\eta_{sl}\Delta_p\Delta_{\phi}\frac{\Delta_\phi}{\chi_L}\right),$$

$$MRB_{S}^{U} - MRB_{L}^{NR} = \lambda - \frac{\lambda}{P_S}\left(q_s\eta_{ls}\Delta_p\Delta_{\phi}\frac{\Delta_\phi}{(1-q_S)\chi_S}\right),$$

Thus, uniform CAFE standards in part raise the marginal benefits to reductions by a uniform amount for each type, but they also have secondary effects that lower the marginal benefits to reductions.

As we observed from the previous theory section, size-based standards tend to mitigate these secondary effects.

$$MRB_{L}^{SBS} - MRB_{L}^{NR} = \lambda - \frac{\lambda}{P_S}\left(q_s\eta_{sl}\Delta_p\frac{(\Delta_\phi - \Delta_\phi)}{\chi_L}\right),$$

$$MRB_{S}^{SBS} - MRB_{L}^{NR} = \lambda - \frac{\lambda}{P_S}\left(q_s\eta_{ls}\Delta_p\frac{(\Delta_\phi - \Delta_\phi)}{(1-q_S)\chi_S}\right),$$

where $\Delta_\phi = \bar{\phi} - \bar{\phi}_S$ is the difference between the uniform standard and the size-based standard for small cars.

And for minimum standards, as we know from the previous section,

$$MRB_{L}^{M} - MRB_{L}^{NR} = \lambda_L$$ and $MRB_{S}^{M} - MRB_{S}^{NR} = \lambda_S$, although the constraint on small cars may not be binding.
To parameterize this simplified model, we draw on existing data and estimates in the literature. From the Wards 2006 model year, we find that average (sales-weighted) prices of small and large cars are $22,562 and $29,422, respectively, with small cars representing 49% of the national automobile fleet. We draw on the recent study by Bento et al. (2006) to calibrate marginal profits. With their markups by manufacturers, we calculate average sales-weighted markups for compact cars of roughly 22%, while markups for mid- and full-sized cars average 25%.

Next, we assume modest, symmetric cross-price elasticities of demand between small and large cars of 0.1, which falls within the range found by Kleit (2002) and Jacobsen (2008) (and will be a target of sensitivity analysis). Then, solving from the price equation (4) for both small and large cars, we use these markups and other parameters to calibrate the own-price elasticities of demand. In other words,

\[
\eta_{LL} = -\frac{B(1 - q_s) + \eta_{LS}m_sq_S}{Bm_s(1 - q_s)}, \quad \eta_{SS} = -\frac{Bn_{LS}m_l(1 - q_s) + q_s}{m_sq_S}
\]

We find that the own-price elasticities consistent with our other parameter assumptions are \(\eta_{LL} = -4.6\), \(\eta_{SS} = -4.7\). Finally, we use a gasoline price of $2.70 per gallon.

With these parameters, we find that

\[
MRB^\text{NR}_L - g\bar{\rho}_L = -0.075\Delta_{\rho}, \quad MRB^\text{NR}_S - g\bar{\rho}_S = 0.180\Delta_{\rho}
\]

In other words, to the extent that small-car consumers are willing to pay more than the average for increased fuel economy, the MRB to the manufacturer increases by an additional 18% of that amount for small cars. Meanwhile, it decreases the MRB for large cars by 8% of that extra small-car consumer willingness to pay. Interestingly, for this representative manufacturer, the distortion for overprovision of fuel economy in small cars is more than twice as large as the underprovision of fuel economy in large cars.

This distribution does depend in good part on the share of small and large cars in the manufacturer’s fleet. On average, small and large cars are fairly evenly represented in the new vehicle market; however, some manufacturers sell much higher proportions of one or the other.
Figure 1 reveals that as the market share of small cars goes up, the fuel economy premium tapers down for small cars (solid line), while it gets increasingly negative for large cars (dashed line). Meanwhile, for producers concentrating on large cars, the underprovision incentive is fairly low, although the incentive to overprovide fuel economy in small cars gets quite large.

**Figure 1: Fleet share of small versus large cars and the fuel economy premium**

![Figure 1](image1)

Another important factor is the assumed cross-price elasticity. The distortions to the marginal reduction benefits increase in proportion to the cross-price elasticity across vehicles. The greater price sensitivity evidently makes quality differentiation more important.

**Figure 2: Sensitivity of the fuel economy premium to cross-price elasticities of small and large cars**

![Figure 2](image2)

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6 The figures assume $\Delta p = 500$. 
On the other hand, the distortions get smaller as the own-price elasticities get larger; this result is evident from the previous equations, since the \( \chi \)'s (the denominators) increase with the own-price elasticities.

The additional distortion from CAFE standards appears to be relatively small. Assuming a rather substantial shadow value of \( \lambda = $2000 \), and a \( \Delta \rho = 0.3 \) from the baseline data, we find that
\[
MRB^U_l - g\bar{\rho}_L = \lambda - 0.084\Delta \rho, \quad MRB^{NR}_s - g\bar{\rho}_S = \lambda + 0.166\Delta \rho.
\]
Thus, CAFE does mitigate some of the fuel economy premium for small cars but exacerbates the distortion for large cars. Of course, this takes the shadow value of fuel economy as given and does not account for the influence of price discrimination on that value. Since the fuel economy premium falls in both cases, given any fleet standard, the shadow value would have to rise, compared to the absence of such a distortion.

Finally, it is worth considering the effect of \( \Delta \rho \) on the overall MRB for each car type. Recall that most models for evaluating CAFE standards and other policies for fuel economy assume that all consumers have the same willingness to pay for fuel economy. Using the NAS study assumptions of annual travel (15,600 miles in the first year, declining by 4.5% annually), vehicle lifetime (14 years), discount rate (5%), and onroad shortfall (15%), this translates into a willingness to pay for a farsighted consumer of $1491 per $1 of gasoline price (or about $4000 at our assumed price of $2.70). By considering that consumers may sort by type and on average have different preferences, MRB will deviate from the average both by the direct effect on willingness to pay and by the additional effect on the fuel economy premium. The results are depicted in Figure 3.
Figure 3: Influence of disparity in willingnes to pay for fuel economy on marginal reduction benefits

Failure to capture this kind of consumer heterogeneity can lead to significant errors in predicting the distribution of effort in complying with CAFE, as well as the calculation and distribution of the benefits.

Policy Discussion

We find that market power gives manufacturers a strategic incentive to over-provide fuel economy in classes whose consumers, on average, value it more than in others, and underprovide it in classes whose consumers value it less than in others. In this manner, manufacturers can better segment their markets and charge higher prices, with less worry that consumers will switch classes.

If one combines this kind of imperfect competition with a second market failure in consumer willingness to pay for fuel economy, a tradeoff in policy prescriptions emerges. Minimum fuel economy standards may better deal with distortions from price discrimination, but they do not provide broad-based incentives for improving fuel economy like average standards. Furthermore, increasing fuel prices can exacerbate both the incentives for price discrimination and the undervaluation of fuel economy. Therefore, a combination policy of both average and minimum standards may be preferred.

Extensions of this research will investigate the effects of market power on fuel economy choice in a more complicated model with multiple manufacturers and vehicle classes. Given the full interdependency of pricing and fuel economy decisions across models, solving such an
equilibrium is much more challenging. However, it offers the opportunity to also gauge the welfare implications of market power distortions and alternative policy interventions.

Another interesting question for future research involves imperfect competition in credit markets, in addition to that in product markets. Obviously, if market power is an issue in the latter, and the same firms are active in the credit markets, then market power is likely to be an issue there as well. The influence is not always clear, since in the credit market, both monopoly and monopsony power may be exercised. Rubin et al. (2006) show that market power in the credit markets can mean that some of the gains from trade are left on the table. This concern is relevant for trading across manufacturers, but not for all of the policy alternatives (e.g., trading across a manufacturer’s car and light truck fleets or switching to feebates). More important, though, is the question of whether it would be relevant for fuel economy decisionmaking.

In general, the results in this paper indicate the importance of additional empirical research on the demand for fuel economy, with greater attention paid to how that might vary by vehicle classes. Indeed, although we have focused on a potential market failure in the supply of fuel economy, a market failure in the demand for fuel economy is the most powerful justification for regulation. Still, few empirical studies consider such complexities in consumer response to fuel costs.

7 See Fischer et al. (2007).
References


New Vehicle Characteristics and the Cost of the Corporate Average Fuel Economy Standard*

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Abstract

Recent legislation has increased the Corporate Average Fuel Economy (CAFE) standard by 40 percent, which represents the first major increase in the standard since its creation in 1975. Previous analysis of the CAFE standard has analyzed the short run effects (1-2 years), in which vehicle characteristics are held fixed, or the long run effects (10 years or more), when firms can adopt new power train technology. This paper focuses on the medium run, when firms can choose characteristics such as weight and power, and have a limited ability to adopt technology. We first document the historical importance of the medium run and then estimate consumers’ willingness-to-pay for fuel efficiency, power and weight. We employ a novel empirical strategy that accounts for the characteristics’ endogeneity, which has not been addressed in the literature, by using variation in the set of engine models used in vehicle models. The results imply that an increase in power has a similar effect on vehicle sales to a proportional increase in fuel efficiency. We then simulate the medium run effects of an increase in the CAFE standard. The policy reduces producer and consumer welfare and causes substantial transfers across firms, but the effects are significantly smaller than found in previous studies.

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The Corporate Average Fuel Economy (CAFE) standard is the minimum fuel efficiency that manufacturers of new vehicles must attain in the U.S. market. After a lengthy period of public debate, the Energy Independence and Security Act of 2007 increased the CAFE standard for new vehicles by about 40 percent, to be effective by the year 2020. The legislation represents the first significant increase in the standard since it was first created in 1975, and followed a period of vigorous public debate. The law’s proponents argued that it would reduce carbon dioxide emissions and oil imports without undermining the automobile industry. Opponents claimed that the costs to vehicle manufacturers and consumers would not justify the benefits, and that other policies would be more effective at reducing emissions and oil imports.

Coinciding with the recent policy debate, a sizeable literature has analyzed the costs to consumers and producers of using the CAFE standard to reduce gasoline consumption. These studies simulate the effect of an increase in the standard on market equilibrium and can be classified into two categories. Some, including Goldberg (1998), have used a short run model, pertaining to one or two years after a change in the standard, in which vehicle characteristics and technology are held constant. Firms respond to an increase in the CAFE standard by adjusting vehicle prices, i.e., by changing the “sales mix.” Other studies, such as Austin and Dinan (2005), use a long run model, which pertains to 10 years or more after a change in the standard, to estimate costs. In this model, firms choose vehicle prices and power train (engine and transmission) technology.

Yet casual observation of the new vehicles market suggests that the preceding analysis is overly simplified. Firms typically select vehicle prices every year and make major changes to power train technology every ten years. But every four or five years, firms can redesign vehicles
by changing their characteristics, such as interior cabin features. Of particular relevance to the CAFE standard is the fact that firms can increase the fuel efficiency of a vehicle by reducing weight and power or by making minor changes to the engine technology. For example, removing components or using lighter materials can reduce the vehicle’s weight. Firms can also modify the engine to reduce the number of cylinders that power the vehicle at low speeds (by contrast, the long run analysis includes major changes to the power train, such as adopting hybrid technology). Relatively minor changes are made routinely in the new vehicles market, and are expected to occur in response to the new CAFE regulation. For example, in the spring of 2008 Honda introduced the 2009 version of the Acura TSX model, which has less power and greater fuel efficiency than the previous version. The Vice President of corporate planning for Honda announced at the time of the introduction that “We feel comfortable there’s plenty of horsepower already and wanted to focus on improving fuel efficiency and emissions. For us generally, you’ll see more of that,” (Ohnsman, 2008). Similarly, GM has announced, “Never mind the fuel cells, plug-ins or diesels. To achieve quick improvements in fuel efficiency, General Motors is adopting an off-the-shelf technology: small engines with turbochargers,” (Kranz, 2008). There is thus a medium run response to the CAFE standard that is distinct from short run price changes and long run technology adoption.

The CAFE literature has concluded that the regulation is far more costly than using the gasoline tax to reduce gasoline consumption. However, because the previous analysis does not incorporate the medium run, total discounted costs may be significantly overstated. To the extent that reductions in weight and power or modifications to the power train are less costly than adjusting the sales mix, actual costs a few years after a change in the standard could be much lower than the short run analysis suggests. Medium run changes in characteristics may also
reduce the need to equip vehicle models with expensive advanced engine technologies in the long run, implying that the long run estimates may also be too high. Finally, the short run/long run distinction may overstate the length of time before significant improvements in fuel economy can be realized. But it is an empirical question whether the medium run is quantitatively important.

We first document the importance of changes in weight and power following the imposition of the initial CAFE standard in 1978. Changes in the sales mix reduced fuel efficiency by a small amount and for only a few years after the standard was imposed. Reductions in weight and power explain much of the increase in fuel efficiency in the late 1970s and early 1980s, after which technology adoption becomes increasingly important. These patterns suggest that the medium run response to CAFE lasts about five years.¹

These results motivate the main analysis, in which we simulate the short and medium run effects of the CAFE standard on market equilibrium. The difference between the short and medium run is that in the short run all vehicle characteristics are fixed, while in the medium run firms choose vehicle prices and characteristics but cannot change the power train technology. As such, this paper is the first to characterize the medium run effects of the regulation. But the analysis of the medium run poses a major empirical challenge, which is to consistently estimate consumers’ willingness-to-pay for characteristics while taking account of their endogeneity. The large literature on consumer demand in the new vehicles market has ignored this issue. For example, Berry, Levinsohn and Pakes (1995) construct a set of instrumental variables that is

¹ A number of studies in the 1980s analyzed the changes in weight, power and fuel efficiency after CAFE was adopted. Similarly to this study, Greene (1987 and 1991) concludes that short run changes in the sales mix explain a small share of the increase in fuel efficiency and that technology explains about half of the increase in fuel efficiency. Greene and Liu (1988) calculate the change in consumer surplus after CAFE was adopted using changes in these characteristics and willingness-to-pay estimates from other studies However, the earlier studies do not perform the analysis at the engine level, as this paper does, and they pertain to a shorter time period.
valid only if characteristics observed by the econometrician are uncorrelated with unobserved
characteristics, which seems unlikely to be the case; e.g., a larger vehicle may have worse
handling.

Several recent studies of other industries have confronted this empirical challenge (e.g., Ishii,
2005), but the new vehicles market poses the additional difficulty that unobserved characteristics
are also endogenous and are potentially correlated with observed characteristics. In this case,
estimation requires an identifying assumption on the joint distribution of the observed and
unobserved variables. For example, Sweeting (2007) assumes that changes in unobserved
characteristics of radio stations occur after the firm has chosen the observed characteristics.\textsuperscript{2} We
use an instrumental variables strategy that is similar to Hausman \textit{et al.} (1994) and exploits a
particular feature of the new vehicles market: firms often sell vehicle models in different vehicle
classes with the same engine. For example, the Ford F-Series (a pickup truck) and the Ford
Excursion (a sports utility vehicle) have the same engine. We instrument for a vehicle’s
endogenous characteristics using the engine characteristics of vehicles located in different
classes that have the same engine. Combined with the estimated demand for fuel efficiency that
we report in Klier and Linn (2008), the results imply that consumers are willing to pay roughly
the same amount for a proportional increase in power as for fuel efficiency.

We use the empirical estimates to simulate the medium run cost of the CAFE standard.
Similarly to the short run analysis, an increase in the CAFE standard causes large transfers across
firms and would particularly harm U.S. firms in the medium run. However, the medium run costs
are about one-half of the short run costs, which implies that the cost of the CAFE standard, in
dollars per gallon of gasoline saved, is much smaller than the short run analysis suggests.

\textsuperscript{2} In Sweeting (2007), unobserved station quality is exogenous, but is potentially correlated with observed
characteristics. Sweeting uses the timing assumption to construct a valid set of instruments using lagged variables.
Furthermore, the long run analysis does not reveal the substantial improvements in fuel efficiency that can be attained only a few years after a new standard is adopted. On the other hand, the cost of reducing gasoline consumption in the medium run is probably greater using the CAFE standard than the cost of using the gasoline tax.

2 Data

This paper uses a detailed data set of vehicle and engine characteristics and vehicle sales from 1975-2008. Klier and Linn (2008) describe the vehicle characteristics and sales data in more detail. Vehicle sales are from the weekly publication Ward’s Automotive Reports for the 1970s and from Ward’s AutoInfoBank in subsequent years. Sales are matched to vehicle characteristics by vehicle model from 1975-2008. The characteristics data are available in print in the annual Ward’s Automotive Yearbooks (1975-2008), and include horsepower, curb weight, length, fuel efficiency and retail price. Note that the data do not include fuel efficiency from 1975-1977, as fuel efficiency was not reported prior to the CAFE program. We impute fuel efficiency from the other vehicle characteristics during these years, using the estimated relationship among characteristics for 1978-1979.

The data coverage for cars is far more extensive than for light trucks. The sample includes all car models produced in the U.S. during the 1970s, but does not have any light trucks in the 1970s. Consequently, the historical analysis in this paper focuses on cars, which account for most of the vehicle market during the late 1970s and early 1980s. According to the U.S. EPA

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3 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 manufacturer suggested retail price (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 for the distribution of the vehicle characteristics by model line (minimum, maximum, mean and median).
(2007), the share of light trucks in the new vehicles market was between 20 and 30 percent between the years 1975 and 1988.

We have obtained data on detailed engine specifications for the years 2000-2008 from CSM, a Michigan-based consulting firm for the automobile sector. The engine data distinguish two levels of aggregation. An engine program refers to a distinct engine technology, and a platform is a collection of related programs. For example, the Volkswagen Passat and Audi A4 are sold with the same engine program. The Volkswagen Jetta has a different engine program from the Passat and the Audi, but both engine programs belong to the same platform. Firms may produce different versions of the same engine program that vary by power and size. Note that engines in the same program have the same number of cylinders, but the number of cylinders may vary across engines in a platform.

For each vehicle model, we construct a list of engine programs that are sold with that model. For a given vehicle, there are three sources of variation over time in the engine technologies that are sold with it. First, the engine may be redesigned, in which case the program identifier changes. Second, firms may discontinue selling a vehicle model with a particular engine, as Honda recently did with the hybrid Accord. Third, a firm can introduce a new version of the vehicle model that is sold with an engine that had previously been sold only with other vehicle models. We have matched engine and vehicle model characteristics for 2000-2008, which limits the estimation of consumer demand for vehicle characteristics to those years; future work will extend the sample to 1995-2008, and possibly further.
3 FUEL EFFICIENCY REGULATION AND ENGINE TECHNOLOGY

3.1 THE CAFE STANDARD

Following the 1973 oil crisis, Congress passed the Energy Policy and Conservation Act in 1975 in order to reduce oil imports. The Act established the CAFE program and required automobile manufacturers to increase the average fuel efficiency of passenger and non-passenger vehicles sold in the United States. There are separate standards for cars and light trucks, which have varied slightly over time; for model-year 2007, the standards are 27.5 miles per gallon (MPG) for cars and 22.2 MPG for light trucks. Firms may also earn credits for over-compliance that can be used in future years. The standards are administered by the U.S. Department of Transportation (DOT) on the basis of the U.S. Environmental Protection Agency’s test procedure for measuring fuel efficiency.

The recently passed Energy Independence and Security Act of 2007 requires DOT to raise fuel-efficiency standards, starting with model year 2011, until they achieve a combined average fuel efficiency of at least 35 mpg for model year 2020. The CAFE standard continues to be extremely controversial, as the 2007 law has been called “a victory for America” (Senator Carper, D-Del, Stoffer 2007), as well as “unnecessary at best and damaging at worst,” (Wall Street Journal op-ed, Ingrassia, 2008). Note that firms are evaluated for compliance with the new standard using a different formula that is based on a vehicle’s “footprint” (the product of length and width).

3.2 CAFE AND MARKET OUTLOOK

As Section 4 shows in more detail, when the original CAFE standard was introduced, automobile manufacturers rather quickly reduced horsepower and weight in order to raise fuel efficiency.

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4 This section draws extensively from National Research Council (2008).
Engine technologies improved over time, which allowed firms to improve a vehicle’s performance while continuing to meet the CAFE standard.

Many industry analysts believe that because many of the “easy” improvements to engine technology were made in response to the initial CAFE standard, the future increase in the standard may be much more costly to producers and consumers. While new power train systems, such as those relying on hybrid electric and diesel technologies, have begun to penetrate the U.S. market, the vast majority of vehicles are powered by conventional gasoline-powered spark-ignition engines. While essentially every vehicle manufacturer is advertising its alternative power train research, as of 2007, sales of hybrid vehicles represent about 2 percent of total sales of cars and light trucks. Thus, once again, the performance characteristics of the existing gasoline engine technology, as well as the related transmission technologies, are the focus of attention.

3.3 The Medium Run

We define the medium run as the period of time in which engine technology is constant, but firms can adjust weight, power and fuel efficiency. In the new vehicle market, the short, medium and long run arise from the timing of firms’ major decisions. Firms typically choose vehicle prices each year, although firms can also offer price incentives during the year. Large changes in vehicle characteristics typically occur every 4-5 years during major model redesigns. Engine technologies change more slowly, as engines are redesigned roughly every 10 years. Thus, following an unexpected increase in the CAFE standard, firms may adjust prices in the short run; weight, power and fuel efficiency in the medium run; and power train technology in the long run.

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5 In that context it is interesting to note that the hybrids available in the market today represent one of two types: mild hybrids (micro-hybrids or integrated starter-generator hybrids) and parallel hybrids. The Toyota Prius and the GM two-mode hybrid fall into the latter category (National Research Council 2008).
More specifically, in the medium run a firm can modify a vehicle in two ways. First, the firm may improve fuel efficiency by reducing weight or power. Using lighter weight components or replacing a six-cylinder engine with a four-cylinder engine would increase fuel efficiency. Note that the former change would likely increase production costs while the latter change might decrease costs; Section 6 returns to this issue.

The second type of modification is that the firm can adopt a limited set of fuel efficiency-improving technologies, which do not require the firm to redesign the engine or transmission. Engines are intentionally designed with this flexibility to allow firms to respond to demand shocks without completely redesigning the power train. Table 1 provides examples of medium and long run changes to the engine or transmission, taken from NHTSA (2008). Relative to the long run changes, the medium run changes are simple to implement and generally cost less, but result in lower fuel efficiency gains.

4 Response to the Initial CAFE Standard
This section documents changes in fuel efficiency, weight and power in the late 1970s and early 1980s. Much of the increase in fuel efficiency during the 5-10 years following the imposition of the initial standard was due to changes in weight and power. This result motivates the use of a medium run model to simulate the effect of CAFE, which is done in sections 5 and 6.

Figure 1 provides summary information on changes in characteristics in the new vehicles market over time. The figure shows the CAFE standard and changes in weight, power and fuel efficiency for all cars sold in the U.S. from 1975-2007, using data reported in U.S. EPA (2007). Average fuel efficiency increased dramatically in the late 1970s and early 1980s as the standard was phased in. During the same period, power and weight decreased and then increased.
The increase in fuel efficiency in Figure 1 could be due to short run changes in the sales mix; medium run changes in power, weight or technology; or the long run adoption of power train technology. This section decomposes the total increase in fuel efficiency into these three effects. The analysis in this section focuses on cars sold by U.S. automobile manufacturers (Chrysler, Ford and GM) for two reasons. First, as Jacobsen (2008) notes, there have been three categories of firms: firms that consistently exceed the standard by a large amount (e.g., Honda and Toyota); firms that are constrained by the standard and typically meet it (e.g., Ford); and firms that consistently pay a fine for not meeting the standard. U.S. firms account for the vast majority of sales from the constrained category, so the response of U.S. firms to the CAFE standard is of particular interest. The second reason for focusing on U.S. cars is that the light truck data are incomplete, and do not allow for a complete analysis for trucks in the 1970s and 1980s.

For comparison with Figure 1, Figure 2 reports fuel efficiency, weight and power of cars sold by U.S. firms. The figure shows that changes in the characteristics of U.S. firms’ cars were similar to the overall market, which reflects the dominance of U.S. firms during this time period. Between 1975 and 1978, which was the first year the CAFE standard was in effect, fuel efficiency increased by about 2 MPG. Gasoline prices were fairly stable during this time period, suggesting that the increase was in anticipation of the standard. It should be recalled, however, that fuel efficiency from 1975-1977 is imputed, and this result should be treated with caution. From 1978 until the early 1980s, fuel efficiency increased by an additional 4 MPG, during which time the U.S. automakers remained above the standard. From the mid 1980s until the end of the sample period, average fuel efficiency was slightly higher than the standard.

At the same time as fuel efficiency was increasing, weight and power were decreasing. Both power and weight decreased by about 25 percent between 1975 and 1982, after which they
increased steadily. In summary, the increase in fuel efficiency following the imposition of the CAFE standard coincided with a large decrease in power and weight. Subsequently, weight and power increased while fuel efficiency did not change.

The remainder of this section assesses the magnitudes of the short, medium and long run responses to CAFE. We first separate the short run from the medium and long run. We abstract from entry and exit decisions and analyze a balanced panel of vehicle models that have positive sales each year from 1975-1984, which Figure 2 shows to be the main period in which fuel efficiency increased. The first data series in Figure 3 is the sales-weighted fuel efficiency of the vehicle models in the sample, which follows a very similar pattern to Figure 2. Two counterfactual series are constructed for this figure, which separate the short run changes in average fuel efficiency from the medium and long run. The first series is the sales-weighted average fuel efficiency, which is calculated using the actual sales of the vehicle models in each year and the fuel efficiency in 1975; this series illustrates the effect of changes in the sales mix, as an increase in the sales of vehicle models that initially have high fuel efficiency would cause the sales-weighted average fuel efficiency to increase. The second series plots average fuel efficiency using the sales weights in 1975 and the actual fuel efficiency of the vehicle model each year, which includes medium and long run changes in fuel efficiency. The short run series shows that changes in the sales mix increased average fuel efficiency by about 0.5 MPG between 1978 and 1981. The other counterfactual series is very close to the average MPG, however, implying that within-model changes in fuel efficiency explain nearly all of the overall change.

6 The models account for about 45 percent of the sales included in the sample in Figure 2.
7 Note that the change in sales-weighted average fuel efficiency equals the sum of the effect of the change in sales mix, plus the effect of within-model changes in MPG, plus a cross-term:
\[ \Delta \bar{M}_t = \sum_j \Delta s_{jt} M_{j0} + \sum_j s_{j0} \Delta M_{jt} + \sum_j \Delta s_{jt} \Delta M_{jt}. \]
Figure 2 reports changes in MPG due to changes in the sales weights and within-model changes in fuel efficiency; i.e., the final term is omitted. In practice, the omitted term explains less than 10 percent of the overall change in all years, and is not shown for clarity.
Thus, within the first 10 years of the introduction of the CAFE standard, firms largely complied by increasing fuel efficiency rather than adjusting the sales mix.

Within-model changes in fuel efficiency in Figure 3 could be due to medium or long run changes in vehicle characteristics and technology. Recall that firms can increase fuel efficiency while holding constant weight and power in both the medium and long run. Unfortunately, detailed engine technology data are not available, and it is not possible to separate medium and long run changes to power trains. However, we can estimate the effect of weight and power on fuel efficiency, which provides a lower bound to the full medium run response.

We first estimate the within-engine technology tradeoff between fuel efficiency, weight and power. We use data from 2000-2008 to estimate the following equation:

\[
\ln M_{jet} = \delta_0 + \delta_1 \ln H_{jet} + \delta_2 \ln W_{jt} + \eta_e + \epsilon_{et}
\]

The dependent variable is the log of the fuel efficiency of vehicle \( j \) with engine \( e \) in year \( t \) and the first two variables are the logs of power and weight. Equation (1) includes engine fixed effects, and the coefficients on power and weight are the within-engine elasticity of fuel efficiency with respect to power and weight; by definition, such changes correspond to the medium run.

Table 2 reports the results of estimating equation (1). The two columns include engine program and engine platform fixed effects (recall that multiple engine programs belong to the same platform). The reported coefficients are the within-program and -platform effects of power and weight on fuel efficiency. The two specifications should be considered to be lower and upper bounds of the medium run effect of weight and power on fuel efficiency. The within-program elasticity of fuel efficiency with respect to power is -0.07 and for weight is -0.33; the estimate for power is larger in column 2 with platform fixed effects. On the other hand, the effect of weight
on fuel efficiency is the same, which is as expected because weight varies at the vehicle level and not the engine level.

Overall, Table 2 suggests that firms can increase fuel efficiency by decreasing power and weight. Assuming the elasticities have not changed over time, we can use the estimated parameters in equation (1) to obtain a lower bound of the medium run response to CAFE. In particular, we use the actual weight and power each year from 1975-2007 for the sample in Figure 2, combined with the estimates in column 1 of Table 2, to predict the fuel efficiency of each vehicle. The predicted series captures medium run changes in weight and power, but does not include medium run technology adoption. The difference between the actual and predicted series can be interpreted as the effect on fuel efficiency of medium and long run technology adoption. Figure 4 shows the actual and predicted fuel efficiency from 1975-2007. The figure demonstrates that decreases in power and weight explain about one-third of the increase in fuel efficiency in the late 1970s and early 1980s. Given that this is probably a lower bound, we conclude that the medium run response to the CAFE standard has been historically important.

5 Estimating Willingness-to-Pay for Engine Power and Weight

This section specifies and estimates the parameters of the market for new vehicles, and the following section reports simulations of an increase in the standard.

5.1 The New Vehicles Market

We model the market for new vehicles, particularly focusing on firms’ choices of vehicle characteristics. The model is static and in each period firms select vehicle prices and

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8 Similarly, Greene (1987) concludes that about half of the increase in fuel efficiency between 1978 and 1985 was due to technology.
characteristics for the vehicles they sell. Consumer demand for each vehicle model depends on its price and characteristics, and each period there is a market clearing vector of prices, quantities and characteristics.

Consumer demand follows a standard nesting structure. We define seven classes based on the vehicle classification system in the Wards database (McManus, 2005). Consumers first decide whether to purchase a vehicle, and then select a class, and finally, a vehicle model. Following Berry (1994), the market share of each vehicle model can be expressed as:

\[ \ln s_{jt} - \ln s_{0c} = \alpha p_{jt} + \beta_D D_{jt} + \beta_H HW_{jt} + \beta_W W_{jt} + \xi_{jt} + \sigma \ln s_{jt|c} \]  

(2)

The left hand side of equation (2) is the difference between the log market share of vehicle model \( j \) and the log market share of the outside good, which is a used vehicle; the denominators in the market shares include new and used vehicles. The first variable on the right hand side is the price of the vehicle model, \( p_{jt} \), and the coefficient \( \alpha \) is the marginal utility of income. The next three independent variables are expected fuel costs, \( D_{jt} \), the ratio of power to weight, \( HW_{jt} \), and weight, \( W_{jt} \). Similarly to Klier and Linn (2008), we define the variable \( D_{jt} \) as dollars-per-mile, which is equal to the price of gasoline divided by the vehicle’s fuel efficiency. The variable is proportional to expected fuel costs if the price of gasoline follows a random walk over the life of the vehicle. Note that the price of gasoline is taken to be exogenous, but the firm can change the expected fuel costs of a vehicle by changing its fuel efficiency. Power-to-weight is a proxy for acceleration, and weight may capture nonlinear effects of acceleration as well as serve as a proxy for safety. This specification allows power-to-weight and weight to enter the utility function separately, while many other studies omit weight, e.g., Petrin (2002).
The next term in equation (2), $\xi_j$, is the average utility derived from the vehicle’s unobserved characteristics. The final term in equation (2) is the log share of the vehicle’s sales in the total sales of the vehicle class, $c$, where $\sigma$ is the within-class correlation of market shares.

The supply side of the model is static, following Berry, Levinsohn and Pakes (1995) (henceforth, BLP). A set of multi-product firms competes in a Bertrand-Nash manner. Each firm is subject to the CAFE standard, that the harmonic mean of its car and truck fleets must exceed particular thresholds. If the firm does not satisfy the constraint it would have to pay a fine, but we assume that in equilibrium the constraint is satisfied exactly; this assumption is not important for the empirical analysis and is relaxed in the simulations.

To compare with the medium run model, we first specify the firm’s optimization problem in a standard short run model. Vehicle characteristics are exogenous and the firm chooses the vector of prices of its set of vehicles $J_f$:

$$\max_{\{p_t\}_{t=1}^{\infty}} \sum_{j \in J_f} (p_{jt} - c(X_{jt}))q_{jt}(p_{jt}, X_{jt}, \xi_{jt})$$

s.t. $\sum_{j \in J_f} q_{jt}(p_{jt}, X_{jt}, \xi_{jt})/C_{jt} \geq \sum_{j \in J_f} q_{jt}(p_{jt}, X_{jt}, \xi_{jt})/M_{jt}$,

where $X_{jt}$ is a vector of (exogenous) characteristics: fuel efficiency, weight and power; and $c(X_{jt})$ is the marginal cost of the vehicle, which depends on the characteristics. The parameter $C_{jt}$ is the CAFE standard that applies to vehicle model $j$ in year $t$.

We now specify the medium run optimization problem, in which firms choose prices and characteristics each period:

$$\max_{\{p_t, X_{jt}, \xi_{jt}, T_{jt}\}_{t=1}^{\infty}} \sum_{j \in J_f} (p_{jt} - c(X_{jt}))q_{jt}(p_{jt}, X_{jt}, \xi_{jt})$$

(MR)
\[
\begin{align*}
\text{s.t. } & \quad \sum_{j\in J_f} q_{jt}(p_{jt}, X_{jt}, \xi_{jt}) / C_{jt} \geq \sum_{j\in J_f} q_{jt}(p_{jt}, X_{jt}, \xi_{jt}) / M_{jt} \\
& \quad \ln M_{jt} = \delta_0 + \delta_1 \ln H_{jt} + \delta_2 \ln W_{jt} + T_{jt} \\
& \quad \ln c_{jt} = \gamma_0 + \gamma_1 \ln H_{jt} + \gamma_2 \ln W_{jt} + \gamma_3 \ln T_{jt}
\end{align*}
\]

Equation (b) specifies that the fuel efficiency of vehicle model \( j \) depends on the engine’s horsepower, the vehicle’s weight and the level of the engine technology. The engine technology is continuous and is scaled so that a unit increase raises log fuel efficiency by one.\(^9\) The marginal cost of the vehicle model is given by equation (c), and depends on the power of the engine, the weight of the vehicle and the engine technology. Note that improving engine technology raises fuel efficiency and therefore demand for the vehicle, but also raises costs; this tradeoff is governed by the coefficient on dollars-per-mile in equation (2) and the cost elasticity in (c). Analogous tradeoffs exist for increasing weight and power. In equilibrium, firms choose the profit-maximizing vectors of prices and vehicle characteristics and consumers choose vehicles based on the prices and characteristics.

The equilibrium depends on supply and demand parameters, but also on the CAFE standard. Similarly to past research, we are interested in the effect of the CAFE standard on the market equilibrium. To answer this question, it is necessary to estimate the parameters in equation (2). Estimating the demand for fuel efficiency, \( \beta_D \), is straightforward, using the same approach as Klier and Linn (2008). Specifically, we use within model-year variation in gasoline prices and sales to estimate \( \beta_D \), which controls for unobserved vehicle model-specific parameters, \( \xi_{jt} \). Identification arises from within model-year variation in fuel costs, but it is not possible to use

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\(^9\) Equation (b) is similar to equation (1) above, but the subscripts are different. Equation (1) is estimated using observations at the engine-vehicle model level. Sales data are only available by vehicle model and year, however, and the analysis in this section is aggregated to that level.
this approach to estimate the coefficients in equation (2) for the variables that do not vary within the model-year, $\alpha$, $\beta_H$, $\beta_W$, and $\sigma$. Therefore, we use the estimate of $\beta_D$ to obtain equation (2'):

$$\ln s_{jt} - \ln s_{0j} - \hat{\beta}_D D_{jt} = \alpha p_{jt} + \beta_H H_{jt} + \beta_W W_{jt} + \xi_{jt} + \sigma \ln s_{jc}$$ (2')

The transformation reduces the number of parameters needed to be estimated.

Estimating equation (2') is far more challenging than in a short run setting. Firms choose the characteristics of each vehicle, taking as given the characteristics of the vehicles sold by other firms in the market. From the first order conditions for (MR), the observed characteristics are correlated with the unobserved characteristics of the same vehicle model, and with both observed and unobserved characteristics of other vehicles. For example, if Honda increases the power of one of its Acura car models, Toyota may increase the power of the Lexus car models that are substitutes for the Acura.

Because of this correlation, estimating equation (2') by Ordinary Least Squares (OLS) would yield biased estimates of all coefficients. The endogeneity of vehicle characteristics implies that three standard approaches would also yield biased estimates. First, including vehicle fixed effects would only address the problem if one assumes that unobserved characteristics do not change over time (i.e., $\xi_{jt} = \xi_{j}$). In that case, the parameters would be identified by within-model changes in prices, power and weight. This assumption is not appropriate because there are many unobserved characteristics, such as interior cabin space, that firms can change as readily as power and weight.

The second approach would be to follow many previous studies of automobile demand, such as BLP, and use moments of vehicle characteristics of other vehicles in the same class or other vehicles sold by the same firm to instrument for the price and within-class market share. The instruments are valid if characteristics are exogenous, in which case the instruments would be
correlated with vehicle prices (via first order conditions in model SR), but would not be
correlated with the unobserved characteristics. Such an argument cannot be made in the medium
run analysis, however, in which characteristics are endogenous. A similar argument can be made
for the third approach, performing a hedonic analysis (e.g., McManus, 2005).

5.2 Estimation Strategy
We use an estimation strategy that is similar in spirit to Hausman et al. (1994), in that we take
advantage of common cost shocks across subsets of the market. The difference is that we use
characteristics of other vehicle models to instrument for characteristics and prices, rather than
instrumenting solely for prices, and we exploit the technological relationships across vehicle
models sold by the same firm.

Many vehicle models in different classes contain the same engines. This practice is common
for SUVs and pickup trucks, but is not confined to those classes; Section 5.3 documents the
prevalence of this behavior across the entire market. As a result, when vehicles in different
classes have the same engines, they have very similar engine characteristics. For example, the
Ford F-Series, a pickup truck, has the same engine as the Ford Excursion, an SUV, and both
vehicles have very similar fuel efficiency and power.

Consider two vehicle models, \( j \) and \( j' \), which have engines \( e \) and \( e' \) that belong to the same
engine platform. The vehicles are in different vehicle classes and the profit-maximizing power of
vehicle \( j \) depends on the cost of increasing power for the particular engine platform, and
similarly for vehicle \( j' \). Therefore, the power of vehicle \( j \) will be a function of the power of
vehicle \( j' \), plus a constant:

\[
H_{je} = f(H_{j'e'}) + \eta_e
\]  
(3)
The power of the two vehicles is correlated because they have the same engine. The class intercepts, $\eta_c$, are arbitrary, potentially nonlinear, functions of the characteristics of other vehicles in the same class, as well as non-engine characteristics of the same vehicle. The intercepts allow for class-specific demand and supply shocks, so that the power of the two vehicles will differ because of variation across classes in consumer preferences and the characteristics of the other vehicles in the respective classes.

The instrumental variables (IV) strategy is based on equation (3), in which we instrument for a vehicle’s price, power-to-weight, weight and within-class market share. The instruments are the means of eight engine characteristics of vehicle models that are located in other classes, but which have the same engine platform. The IV strategy yields unbiased estimates of the demand for power and weight if the error term in equation (3) is uncorrelated across classes for vehicles that have the same engine. Note that this assumption is considerably weaker than the standard assumption that observed and unobserved characteristics are uncorrelated.

Although this approach relaxes the assumption that vehicle characteristics are exogenous, there are several potential sources of bias. First, there may be unobserved brand-specific fixed effects or trends, which would cause $\eta_c$ to be correlated across classes. To address this concern, the specification includes brand-year interactions; for example, the approach would be robust if

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10 The instruments are listed in Appendix Table 1 and include fuel efficiency, power, weight, power-to-weight, torque, the number of valves, the number of cylinders and displacement. The instruments are calculated as the mean deviation from the class mean to account for the class intercepts in equation (3). The results are similar if means rather than mean deviations are used to construct the instruments. We prefer to construct the instruments using engine platforms rather than engine programs because the sample size is much larger and the instruments for a particular vehicle are constructed from a wider range of other vehicles, which probably reduces bias. Note that the results are sensitive to this distinction, however, as the demand for power is small and not statistically significant using program-based instruments.

11 We assume that demand is uncorrelated across vehicle classes. Strictly speaking, this is not the case in the nested logit framework, but cross-class demand elasticities are second order in magnitude.

12 Estimating equation (2') is preferable to equation (2) because the same set of instruments is available for both equations, but (2') has one less endogenous variable. An additional advantage is that power, weight and fuel efficiency are highly correlated with one another, making it difficult to obtain robust estimates of the coefficients on dollars-per-mile, power and weight if all variables are included in the IV estimation.
all Honda models share common unobserved characteristics. Second, the estimates would be biased if there were unobserved engine characteristics. However, we believe that the included variables in equation (2’) capture the main features that consumers use to differentiate engines, as the results are robust to adding other engine characteristics, such as the number of cylinders or the engine’s torque. Finally, the decision to use a particular engine in a vehicle model may be endogenous. The identifying assumption is that the correlation of characteristics across vehicle models is driven by the common engine technology, but this may not be valid if unobserved vehicle characteristics are also correlated across models with the same engine. We can partially address this issue by using lagged engine characteristics as instruments, which takes advantage of the fact that engines are redesigned at longer time scales than the rest of the vehicle. Consequently, the correlation between the instruments and endogenous variables is more likely to be driven by a common engine technology, rather than common unobserved characteristics. The results are not sensitive to using lagged values to construct the instruments (see section 6.3 and Table 7 for robustness checks).

5.3 Variation in Engines and First Stage Results

Before reporting the results of estimating equation (2’), we summarize the engine variation across vehicle models and discuss the first stage estimates for equation (2’). Each row in Table 3 includes a different vehicle class. Column 1 shows the number of vehicle models in 2008 and column 2 shows the number of vehicle models in the sample for 2008. The sample only includes vehicles that have an engine found in a vehicle from a different vehicle class, i.e., for which the instruments can be constructed. Only about two-thirds of the vehicles are in the sample, but columns 3 and 4 show that the sample includes 87 percent of total sales. Furthermore, except for
small cars, the sample includes nearly all of the sales for each class. It is important to note that it would be possible to increase the sample size by defining narrower vehicle classes. There is a tradeoff between sample size and bias, however, because with narrower classes it is more likely that demand shocks are correlated across classes, invalidating the IV approach.

Table 4 reports summary statistics for the dependent variable and four endogenous right-hand-side variables in equation (2’). For the final estimation sample, the two columns show the means and standard deviations of the variables. Price is reported in thousands of dollars, power-to-weight is measured in horsepower per pound and weight is in tons.

Appendix Table 1 reports the first stage estimates. The dependent variables are the four endogenous variables from Table 4. All specifications include brand-year interactions and the reported engine-based instruments. The instruments are jointly strong predictors of the endogenous variables.

5.4 THE DEMAND FOR POWER AND WEIGHT

Table 5 reports the estimates of the demand for power and weight from equation (2’). The dependent variable is the log of the vehicle model’s market share and the independent variables are the price of the vehicle, power-to-weight, weight, the within-class market share and a set of brand-year interactions.

Column 1 reports the OLS estimates of (2’) for comparison with the IV estimates. The coefficient on the price of the vehicle is statistically significant but is small in magnitude, as the average own-price elasticity of demand is -0.16. The coefficient on power-to-weight is negative and is not significant. The price coefficient is likely biased towards zero because the price should be positively correlated with unobserved variables, but the direction of the bias for the
characteristics is ambiguous because they may be positively or negatively correlated with unobserved characteristics.

Previous studies, such as BLP, use observed vehicle characteristics to instrument for the vehicle’s price. As noted above, this approach is only valid if the instruments are uncorrelated with the unobserved characteristics. Column 2 of Table 5 reports a specification that follows the previous literature and uses other characteristics as instruments, in particular, the sum of the characteristics of other vehicles in the same class and the sum of characteristics of other vehicles sold by the same firm. The coefficient on the vehicle’s price is larger in magnitude than the OLS estimate, and implies an average elasticity of demand of -2.02, which is somewhat smaller than previous studies. The coefficient on power-to-weight is close to zero, however.

Column 3 reports the baseline specification using the engine-based instruments. The estimated coefficient on the vehicle’s price is larger than the other estimates and the average elasticity of demand is -2.6. The coefficient on power-to-weight is much larger and is statistically significant. The estimate implies that a one percent increase in power raises willingness-to-pay for the average vehicle by about the same as a one percent increase in fuel efficiency. Because of the steep technological tradeoff between power and fuel efficiency (see Table 2), this result is consistent with Figures 2 and 4, which show that as engine technology improved, firms have increased power and weight while keeping fuel efficiency constant.

5.5 Effect of Changes in Characteristics on Willingness-to-Pay for U.S. Cars

If the demand for weight and power is sufficiently large relative to the demand for fuel efficiency, the decrease in weight and power in the late 1970s and 1980s for U.S. cars would have reduced willingness-to-pay for these vehicles. Figure 5 plots the change in willingness-to-
pay for the average car sold by U.S. firms from 1975-2007, using the characteristics in Figure 2, the estimates from column 3 of Table 5, and holding the price of gasoline fixed. The figure shows that willingness-to-pay decreased soon after CAFE was implemented, but increased steadily beginning around 1980.\textsuperscript{13} Note that the willingness-to-pay calculations are properly interpreted as the effect of the CAFE standard on willingness-to-pay only if all characteristics and prices would have remained constant in the absence of the policy. Thus, Figure 5 does not allow for an inference about the causal effect of CAFE, but is useful for summarizing the relative demand for fuel efficiency, power and weight.

6 SIMULATION RESULTS AND INTERPRETATION

This section uses the empirical estimates from Section 5 to compare the short and medium run costs of the CAFE standard. We simulate the equilibrium under a 2 MPG increase in the CAFE standard for all vehicles.

6.1 SHORT RUN EFFECTS OF AN INCREASE IN THE CAFE STANDARD

In the simulation model firms maximize profits subject to the CAFE standard. For comparison with the previous literature and with the medium run analysis, we first simulate the short run effects of the CAFE standard. The model is summarized in Section 5.1. Firms choose a vector of prices to maximize profits subject to the CAFE standard. Firms are separated into three categories: unconstrained firms that exceed the standard, constrained firms that meet the standard, and firms that pay the fine for not meeting the standard. Firms are assigned to the three categories based on past behavior. Honda, Toyota and several smaller Asian firms have

\textsuperscript{13} Greene and Liu (1988) perform a similar analysis and reach the same conclusion using estimates of willingness-to-pay for characteristics from other studies performed in the 1970s and 1980s.
consistently exceeded the standard by a wide margin and are unconstrained; Chrysler, Ford and GM and a few other firms have generally been close to the standard and are constrained; and all other firms have been well below the standard. The constrained firms solve problem (SR), while the other firms do not have a constraint; unconstrained firms that do not satisfy the constraint pay a fine. In performing the simulations, we assume that firms do not change categories as a result of the increase in the standard.

Table 6 shows the estimated effects of a 2 MPG increase in the CAFE standard. The columns report the changes in consumer surplus, total profits, profits of U.S. firms, market share of U.S. firms, overall fuel efficiency, horsepower and weight. Consumer surplus declines by about $19 billion because of the changes in vehicle prices under the increased standard. Total profits decrease by about $17 billion. Columns 3-5 show that the increase in the standard causes a transfer in profits from U.S firms to Honda and Toyota, which can be explained as follows. In response to the higher CAFE standard, U.S. firms must change their sales mix in order to increase average fuel efficiency. The resulting price changes cause consumers to substitute to competing vehicle models, which increases the profits of firms that are not constrained by the new standard. The table shows that the increase in the CAFE standard raises average fuel efficiency by less than 2 MPG because many firms are not constrained and do not increase fuel efficiency. Finally, power and weight decrease because constrained firms adjust prices so that consumers purchase more fuel efficient vehicles, which tend to be less powerful and lighter.
6.2 MEDIUM RUN EFFECTS (PRELIMINARY)

The second row of Table 6 reports the results of simulating a 2 MPG increase using the medium run model from Section 5.1, (MR). All firms choose prices and vehicle characteristics to maximize profits. Firms are classified among the same three categories as before.

The medium run simulation model includes two important differences from the short run model. First, each vehicle’s fuel efficiency is endogenous and depends on weight, power and technology. The simulation uses the elasticities of fuel efficiency with respect to power and weight that were estimated in Section 4.

The second difference of the medium run model is that marginal costs are now endogenous. Because firms do not change characteristics in the short run, marginal costs are not affected by the CAFE standard in the short run. However, marginal costs play an important role in the medium run analysis. For example, if marginal costs increase significantly when firms reduce weight, firms would be unlikely to do so. We assume a CES cost function, where the elasticity of costs to power is estimated using proprietary engine cost data. Similarly to Austin and Dinan (2005), the elasticities of costs to weight and engine technology are estimated using data on the costs and efficacy of engine and weight reduction technologies from NHTSA (2008). It is important to note that in the medium run analysis, only a limited set of engine technologies can be adopted. Therefore, the elasticity of costs to engine technology is greater in the medium run than in the long run (the short run elasticity is infinite).

The second row of Table 6 reports summary statistics from a preliminary simulation of the medium run effects of the standard. The differences between the short and medium run

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14 We assume throughout that there are no economies of scale, so that marginal costs only depend on vehicle characteristics.
15 The constant terms in the cost and technology equations are estimated using the initial fuel efficiency and marginal cost of each model (i.e., before the increase in the standard). The final fuel efficiency and marginal cost are calculated using the deviations from the initial values of power, weight and technology.
simulations underscore the importance of accounting for the endogeneity of vehicle characteristics. The overall changes in producer and consumer surplus are roughly half as large in the medium run as in the short run. This result is consistent with Jacobsen (2008), who finds that the long run cost is roughly one-third of the short run cost, so that the medium run costs lie between the two extremes. Section 4 suggests that short run changes in the sales mix are important for at most one or two years, while medium run changes in vehicle characteristics are important for roughly 5 years. Thus, previous studies significantly overstate the annual cost of the CAFE standard for horizons of about 2-5 years.

Many previous studies compare the cost of reducing gasoline consumption using the gasoline tax with the cost of using the CAFE standard. Although the medium run costs of the CAFE standard are much lower than the short run costs, the magnitudes do not overturn the conclusions of other studies that the gasoline tax is much less costly than the CAFE standard. Jacobsen (2008) finds that the short run cost of the gasoline tax is roughly one-sixth the cost of the CAFE standard. Therefore, even in the medium run, CAFE is more expensive than the gasoline tax.

6.3 Robustness and Limitations

Table 7 reports a number of robustness checks for equation (2’). Columns 1-4 assess the importance of including brand-year interactions, add vehicle class-year interactions and address potential serial correlation. The coefficient on power-to-weight is considerably smaller if class-year interactions are added to equation (2’). Columns 5 and 6 address functional form assumptions by including power and weight separately and adding other engine characteristics on the right-hand-side; the results are similar in both cases. Column 7 shows that the estimated coefficient on power-to-weight is smaller if additional instruments are included. The estimate is
not affected using lagged instruments (columns 8 and 9), which addresses the potentially endogenous choice of which engines are paired with which vehicles (see Section 5.3). Overall, the results are somewhat sensitive to the alternative specifications, although the estimate on power-to-weight is positive in all specifications and is statistically significant in most. We use the specification in Table 5 for the simulations because of the relatively large estimate on power-to-weight. The fact that the large estimate is used implies that the decrease in costs between the short and medium run may be at least as large as reported in Table 6.

We believe that the sensitivity of estimated willingness-to-pay to alternative specifications has not been emphasized enough in the previous literature, where the standard practice is to report one or two specifications. Furthermore, Appendix Table 2 shows that the BLP specification is at least as sensitive as the engine-based specification.

A few limitations of the analysis should be noted. The model used to perform the simulations uses the original structure of the CAFE standard, which was based on the harmonic mean of a firm’s fuel efficiency for cars and light trucks. Future work will incorporate the new version of the standard, which is based on a vehicle’s footprint. More difficult to address is the assumption in the simulations that unobserved characteristics do not change in response to the increase in the standard.

Finally, the policy scenario discussed above considers the medium run effect of the CAFE standard, in which there is no entry (exit is modeled in the simulation, however). Explicitly allowing for the entry of vehicle models is a potential direction for future research.
The upcoming increase in the CAFE standard will significantly affect the new vehicles market. This paper analyzes the medium run effect of the standard, which we define as the response when engine technology is held constant but firms can change vehicle characteristics. This paper first shows that in response to the initial standard, firms significantly reduced the power and weight of vehicles sold in the late 1970s and early 1980s in order to increase fuel efficiency, but technological progress caused power to recover in the long run.

We then estimate consumers’ demand for power and weight in order to analyze the medium run effects of the CAFE standard. Estimating demand is complicated by the fact that firms select vehicle characteristics endogenously, which previous empirical work has not addressed. We propose an instrumental variables strategy that controls for endogenous and time-varying unobserved characteristics. The estimates suggest that consumers value an increase in power roughly the same as a proportional increase in fuel efficiency. We use a static model of the new vehicles market to simulate the effect of an increase in the standard. The policy causes considerable transfers from constrained firms (U.S. firms, for the most part) to other firms. The medium run costs are substantially lower than the short run costs, however. Given the small role of changes in the sales mix documented in Section 4, this result implies that the short run analysis substantially overestimates the cost of the regulation. Furthermore, the results suggest that firms can attain larger improvements in fuel efficiency in a shorter amount of time than is suggested by a long run analysis. That is, both the short and long run analysis likely overstate the total discounted cost of the CAFE regulation by a significant margin. However, the magnitudes reported in this paper still do not suggest that the CAFE standard compares favorably to a gasoline tax in terms of the cost of reducing gasoline consumption.
REFERENCES


25 Ward’s AutoInfoBank, Ward’s Automotive Group.
Table 1
Examples of Medium and Long Run Engine and Transmission Changes

<table>
<thead>
<tr>
<th>Technology</th>
<th>Medium Run</th>
<th>Percent Increase in MPG</th>
<th>Technology</th>
<th>Long Run</th>
<th>Percent Increase in MPG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Friction Lubricants</td>
<td>3</td>
<td>0.5</td>
<td>Turbocharge/Downsize</td>
<td>120</td>
<td>5-7.5</td>
</tr>
<tr>
<td>Variable Valve Timing</td>
<td>59-209</td>
<td>1-3</td>
<td>Continuously Variable Trans</td>
<td>139</td>
<td>3.5</td>
</tr>
<tr>
<td>5-speed Automatic Transmission</td>
<td>76-167</td>
<td>0.5-2.5</td>
<td>Automatic Manual Transmission</td>
<td>141</td>
<td>4.5-7.5</td>
</tr>
<tr>
<td>Cylinder Deactivation</td>
<td>203</td>
<td>4.5-6</td>
<td>PHEV</td>
<td>6750</td>
<td>28</td>
</tr>
</tbody>
</table>

Table 2

Tradeoff Between Fuel Efficiency, Weight and Power for Cars

<table>
<thead>
<tr>
<th>Dependent Variable: Log Fuel Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
</tr>
<tr>
<td>Log Horsepower</td>
</tr>
<tr>
<td>-0.06</td>
</tr>
<tr>
<td>(0.03)</td>
</tr>
<tr>
<td>Log Weight</td>
</tr>
<tr>
<td>-0.33</td>
</tr>
<tr>
<td>(0.07)</td>
</tr>
<tr>
<td>R²</td>
</tr>
<tr>
<td>0.90</td>
</tr>
<tr>
<td>Number of Observations</td>
</tr>
<tr>
<td>1989</td>
</tr>
</tbody>
</table>

Notes: Standard errors in parentheses, clustered by engine. Observations are by engine and year for 2000-2007. All specifications are estimated by Ordinary Least Squares. The dependent variable is the log of the fuel efficiency of the corresponding vehicle model. All columns include the log of the engine's power and the log of the vehicle model's weight. Column 1 includes engine program dummies and column 2 includes engine platform dummies.
<table>
<thead>
<tr>
<th>Vehicle Class</th>
<th>Number of Vehicle Models</th>
<th>Number of Vehicle Models with Instruments</th>
<th>Fraction Sales</th>
<th>Fraction Sales with Instruments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small Cars</td>
<td>36</td>
<td>15</td>
<td>0.16</td>
<td>0.10</td>
</tr>
<tr>
<td>Mid-Size Cars</td>
<td>38</td>
<td>22</td>
<td>0.20</td>
<td>0.19</td>
</tr>
<tr>
<td>Large, Luxury and Specialty Cars</td>
<td>68</td>
<td>46</td>
<td>0.12</td>
<td>0.10</td>
</tr>
<tr>
<td>Small SUVs</td>
<td>56</td>
<td>40</td>
<td>0.18</td>
<td>0.16</td>
</tr>
<tr>
<td>Large SUVs</td>
<td>43</td>
<td>34</td>
<td>0.11</td>
<td>0.11</td>
</tr>
<tr>
<td>Vans</td>
<td>15</td>
<td>10</td>
<td>0.07</td>
<td>0.06</td>
</tr>
<tr>
<td>Pickup Trucks</td>
<td>21</td>
<td>18</td>
<td>0.16</td>
<td>0.16</td>
</tr>
<tr>
<td>Total</td>
<td>277</td>
<td>185</td>
<td>1.00</td>
<td>0.87</td>
</tr>
</tbody>
</table>

Notes: Vehicles are assigned to the vehicle classes, which are defined in the Wards database. The number of vehicle models is the number of unique models in each class in the 2008 model-year. The number of vehicle models with instruments is the number of models for which there is another model that belongs to a different class and has the same engine. Fraction sales is the share of sales of vehicle models in the class in total sales in the 2008 model-year. Fraction sales with instruments is the fraction of sales in total sales for the vehicle models with instruments.
<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Log Market Share</td>
<td>-4.717</td>
<td>1.490</td>
</tr>
<tr>
<td>Vehicle Price</td>
<td>33.192</td>
<td>18.002</td>
</tr>
<tr>
<td>Power-to-Weight</td>
<td>0.059</td>
<td>0.014</td>
</tr>
<tr>
<td>Weight</td>
<td>1.911</td>
<td>0.421</td>
</tr>
<tr>
<td>Log Within-Class Market Share</td>
<td>-4.076</td>
<td>1.445</td>
</tr>
</tbody>
</table>

Notes: The table reports the mean and standard deviation of log market share, vehicle price (thousands of dollars), power-to-weight (horsepower per pound), weight (tons) and the log of the within-class market share.
# Table 5

### Willingness-to-Pay for Power and Weight

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dependent Variable: Log Market Share</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vehicle Price</td>
<td>-0.004</td>
<td>-0.026</td>
<td>-0.050</td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td>(0.007)</td>
<td>(0.017)</td>
</tr>
<tr>
<td>Power-to-Weight</td>
<td>4.656</td>
<td>1.544</td>
<td>32.785</td>
</tr>
<tr>
<td></td>
<td>(0.977)</td>
<td>(4.752)</td>
<td>(10.686)</td>
</tr>
<tr>
<td>Weight</td>
<td>0.603</td>
<td>0.895</td>
<td>1.350</td>
</tr>
<tr>
<td></td>
<td>(0.030)</td>
<td>(0.132)</td>
<td>(0.295)</td>
</tr>
<tr>
<td>Log Within-Class Share</td>
<td>0.924</td>
<td>0.420</td>
<td>0.628</td>
</tr>
<tr>
<td></td>
<td>(0.010)</td>
<td>(0.070)</td>
<td>(0.120)</td>
</tr>
<tr>
<td>R²</td>
<td>0.96</td>
<td>0.83</td>
<td>0.88</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Estimation Model</strong></td>
<td>OLS</td>
<td>IV, BLP Instruments</td>
<td>IV, Engine Instruments</td>
</tr>
<tr>
<td>N</td>
<td>1804</td>
<td>1804</td>
<td>1804</td>
</tr>
</tbody>
</table>

Notes: The table reports the results from estimating equation (2'). Standard errors are in parentheses, robust to heteroskedasticity. The dependent variable is the difference between the log share of sales of the vehicle model in total sales, and the log share of sales of used vehicles in total sales, where total sales include used and new vehicles. The independent variables are the price of the vehicle, in thousands of dollars; power-to-weight, in horsepower divided by weight, in pounds; weight, in tons; the log of the within class share of sales; and a full set of brand-year interactions. Column 1 is estimated by Ordinary Least Squares and columns 2 and 3 are estimated by Instrumental Variables. Column 2 instruments for vehicle price using the sum of characteristics of vehicle models in the same category produced by other firms and the sum of characteristics of other models produced by the firm. Column 3 uses as instruments the independent variables in the Appendix Table.
### Table 6: Effects of a 2 MPG Increase in the CAFE Standard

<table>
<thead>
<tr>
<th></th>
<th>Change in Cons Surplus (Billion $)</th>
<th>Change in Total Profits (Billion $)</th>
<th>Change in U.S. Firms’ Profits (Billion $)</th>
<th>Change in Profits for Honda/Toyota (Billion $)</th>
<th>Percent Change in U.S. Market Share</th>
<th>Change in Fuel Efficiency (MPG)</th>
<th>Change in Horsepower</th>
<th>Change in Weight (Pounds)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Short Run</strong></td>
<td>-19.37</td>
<td>-17.46</td>
<td>-25.43</td>
<td>7.68</td>
<td>-8.82</td>
<td>1.33</td>
<td>-11.36</td>
<td>-184.46</td>
</tr>
<tr>
<td><strong>Medium Run</strong></td>
<td>-8.16</td>
<td>-8.18</td>
<td>-8.26</td>
<td>2.14</td>
<td>-3.46</td>
<td>1.42</td>
<td>-24.11</td>
<td>-421.19</td>
</tr>
</tbody>
</table>

Notes: The table reports the effect of a 2 MPG increase in the CAFE standard on consumer surplus total profits, profits of U.S. firms, profits of Honda and Toyota (all in billions of 2007 dollars), the percent change in market share of U.S. firms, and the change in fuel efficiency (MPG), the change in horsepower and the change in weight (pounds). The two rows report the results of different simulations. In the first row, weight, power and fuel efficiency of each vehicle model are held constant, while in the second row these characteristics are chosen by the firm. See text for details on the simulations.
<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
<th>(7)</th>
<th>(8)</th>
<th>(9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle Price</td>
<td>-0.051</td>
<td>0.001</td>
<td>-0.050</td>
<td>-0.004</td>
<td>-0.058</td>
<td>-0.050</td>
<td>-0.028</td>
<td>-0.034</td>
<td>-0.081</td>
</tr>
<tr>
<td>(0.017)</td>
<td>(0.005)</td>
<td>(0.030)</td>
<td>(0.012)</td>
<td>(0.021)</td>
<td>(0.017)</td>
<td>(0.008)</td>
<td>(0.023)</td>
<td>(0.047)</td>
<td></td>
</tr>
<tr>
<td>Power-to-Weight</td>
<td>33.100</td>
<td>6.646</td>
<td>32.785</td>
<td>21.003</td>
<td>23.990</td>
<td>20.943</td>
<td>39.913</td>
<td>66.969</td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td>1.377</td>
<td>0.483</td>
<td>1.350</td>
<td>0.214</td>
<td>0.485</td>
<td>0.026</td>
<td>1.020</td>
<td>1.104</td>
<td>1.726</td>
</tr>
<tr>
<td>(0.299)</td>
<td>(0.103)</td>
<td>(0.536)</td>
<td>(0.238)</td>
<td>(0.248)</td>
<td>(0.541)</td>
<td>(0.129)</td>
<td>(0.307)</td>
<td>(1.888)</td>
<td></td>
</tr>
<tr>
<td>Log Within-Class Share</td>
<td>0.620</td>
<td>0.968</td>
<td>0.628</td>
<td>0.421</td>
<td>0.591</td>
<td>0.819</td>
<td>0.781</td>
<td>0.718</td>
<td>0.367</td>
</tr>
<tr>
<td>(0.125)</td>
<td>(0.029)</td>
<td>(0.223)</td>
<td>(0.119)</td>
<td>(0.137)</td>
<td>(0.076)</td>
<td>(0.060)</td>
<td>(0.204)</td>
<td>(0.366)</td>
<td></td>
</tr>
<tr>
<td>Lag Dep Var</td>
<td>0.565</td>
<td>0.010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>1804</td>
<td>1804</td>
<td>1804</td>
<td>1496</td>
<td>1804</td>
<td>1804</td>
<td>1804</td>
<td>1089</td>
<td>1151</td>
</tr>
<tr>
<td>Spec</td>
<td>Year and Brand Dummies</td>
<td>Add Class-Year Interactions</td>
<td>Cluster by Model</td>
<td>Add Lag Dep Var</td>
<td>Separate Power, Weight</td>
<td>Add Torque and Disp</td>
<td>Other Engine Instr</td>
<td>3-yr Lagged Instr</td>
<td>Lagged 3-yr Mean Instr</td>
</tr>
</tbody>
</table>

Notes: The table reports the specifications indicated in the bottom row, using column 3 of Table 5 as the baseline. Standard errors are robust to heteroskedasticity, except in column 3 where standard errors are clustered by vehicle model. Column 1 includes brand and year dummies instead of brand-year interactions. Column 2 adds vehicle class-year interactions, and does not demean the instruments. Column 4 includes the lag of the dependent variable. Column 5 includes weight and power separately. Column 6 adds torque and displacement (not reported). Column 7 uses additional instruments for vehicle price, log within-class market share and length, which are constructed similarly to the other instruments. Column 8 uses the 3-year lags of the instruments from the corresponding engine platform, and column 9 uses the means of the instruments from 2, 3 and 4 years earlier.
### First Stage Estimates

<table>
<thead>
<tr>
<th></th>
<th>Dependent Variable:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Vehicle Price (Thousand $)</td>
</tr>
<tr>
<td>Fuel</td>
<td>-0.168 (0.082)</td>
</tr>
<tr>
<td>Efficiency</td>
<td>-0.107 (0.034)</td>
</tr>
<tr>
<td>Power-to-Weight</td>
<td>-0.041 (0.040)</td>
</tr>
<tr>
<td>Weight</td>
<td>0.054 (0.031)</td>
</tr>
<tr>
<td>Torque</td>
<td>0.945 (0.126)</td>
</tr>
<tr>
<td>Number of Valves</td>
<td>0.840 (0.915)</td>
</tr>
<tr>
<td>Number of Cylinders</td>
<td>0.006 (0.002)</td>
</tr>
<tr>
<td>Displacement</td>
<td>0.006 (0.002)</td>
</tr>
</tbody>
</table>

Notes: Instruments for vehicle price, power-to-weight, weight, and within-class market share are constructed from the matched engine model-vehicle model data set. The instruments are the mean of within-class deviations of vehicles belonging to other classes that have the same engine. The sample includes all models for which the instruments can be calculated, and spans 2000-2008. The table reports coefficient estimates with standard errors in parentheses. All regressions include brand-year interactions. Standard errors are robust to heteroskedasticity. For readability, the power-to-weight instrument is divided by 1000, coefficients in column 2 are multiplied by 1000, and the coefficients in columns 3 and 4 are multiplied by 100.
### Appendix Table 2

**Alternative Specifications With BLP Instruments**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Dependent Variable: Log Market Share</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
</tr>
<tr>
<td>Vehicle Price</td>
<td>-0.070</td>
</tr>
<tr>
<td></td>
<td>(0.014)</td>
</tr>
<tr>
<td>Power-to-Weight</td>
<td>29.738</td>
</tr>
<tr>
<td></td>
<td>(9.071)</td>
</tr>
<tr>
<td>Power</td>
<td>1.710</td>
</tr>
<tr>
<td></td>
<td>(0.262)</td>
</tr>
<tr>
<td>Weight</td>
<td>0.430</td>
</tr>
<tr>
<td></td>
<td>(0.074)</td>
</tr>
<tr>
<td>Log Within-Class Share</td>
<td>0.694</td>
</tr>
<tr>
<td>Lag Dep Var</td>
<td>0.694</td>
</tr>
<tr>
<td></td>
<td>(0.061)</td>
</tr>
<tr>
<td>R²</td>
<td>0.76</td>
</tr>
<tr>
<td>N</td>
<td>1804</td>
</tr>
</tbody>
</table>

Notes: The table reports the specifications indicated in the bottom row. All specifications are the same as the corresponding columns in Table 7, except that the BLP instruments from column 2 of Table 5 are used, rather than the engine-based instruments.
Notes: Figures are constructed using data reported in U.S. EPA (2007).
Notes: Figure 2a reports the sales-weighted mean fuel economy (in MPG), weight (in pounds) and horsepower (multiplied by 10) of all cars sold by U.S. companies for each year. Figure 2b reports the percent change in each variable, relative to 1975.
Figure 3: The Effect of Changes in Sales and Fuel Efficiency, Balanced Panel of U.S. Cars, 1975-1984

Notes: Actual MPG is the sales-weighted mean MPG of all cars sold by U.S. firms that have positive sales for each year, 1975-1984. The initial MPG series is the sum of the actual MPG in 1975 and the inner product of the change in sales weights and the 1975 MPG of each vehicle model. The actual MPG series is the sum of the actual MPG in 1975 and the inner product of the change in MPG of each vehicle model with the 1975 sales weight. See text for details.
Figure 4: Effect of Power and Weight on Fuel Efficiency for U.S. Manufacturers, 1975-2008

Notes: The actual MPG series is the same series as reported in Figure 2. The change in predicted MPG is calculated using equation (1), the estimated coefficients reported in column 1 of Table 2 and the change in sales-weighted power and weight from Figure 2. The characteristics-based MPG is equal to the sum of the actual MPG in 1978 and the change in predicted MPG.
Notes: The figure plots the change in willingness-to-pay for U.S. cars, using 1975 as the baseline year. Change in willingness-to-pay is calculated using the change in sales-weighted power and weight from Figure 2 and the estimates from column 3 of Table 5.
Is the Auto Market Getting Fuel Economy Right?
Comments on Fischer, Klier & Linn

Gloria E. Helfand
Office of Transportation & Air Quality
U.S. Environmental Protection Agency

The views expressed in this paper are those of the authors and do not necessarily represent those of the US Environmental Protection Agency. This paper has not been subjected to EPA’s review process and therefore does not represent official policy or views.
What I’ll quickly take from Fischer

- A gas tax increases fuel economy but increases distortions
- A minimum fuel economy standard raises an interesting alternative to a CAFE standard
- A “footprint” CAFE standard may lead to less distortion than a “uniform” CAFE standard.
A Few (Random) Observations

- Why isn’t price a function of fuel economy too, instead of asserting a willingness to pay for fuel economy independently?
- The policies don’t actually aim for a target fuel consumption or other environmental goal to be on the same footing.
- Is there a story here related to actual behavior?
  - Hummers could have better fuel economy
  - Priuses have more than they should
What I’ll quickly take from K&L

- Further evidence that automakers put effort into power, not fuel economy
- Fuel economy technology is likely to be cheaper than changing market shares to achieve fuel economy standards
- Comparison of short- and medium-runs
  - Allowing time for technology changes reduces costs substantially – approximately 50%.
- Effects on domestic automakers
  - Since they’re the only ones constrained by CAFE, they’re worse off from tightening fuel economy
A Few (Random) Observations

- Why is fuel economy a function of horsepower & weight?
  - It implies that it’s determined by the exogenous choices of HP & weight, not a choice by itself.

- What’s the value of fuel economy used in the fuel cost calculation?
  - Do people get the value “right”?
  - It is a little odd to see a key parameter vanish via subtraction from the estimated equation

- Data sets from different sets of years
  - Fuel economy-HP-weight equation uses 2000-2008 data
  - Counterfactuals use 1975-1984 data
  - Unclear what data used for estimation

- Simulations assume fuel economy averaging over all manufacturers, not within manufacturers

- Is the dependent variable both positive and negative?
  - Where does the share of used cars come from?
Policy Perspective: What do consumers want?

- Do consumers buy the cost-minimizing amount of fuel economy?
  - Do consumers view fuel economy as only a component of the cost of driving?
  - Is fuel economy a vehicle attribute not subject to the same constrained behavior?

- How well can we explain what vehicles people buy?
  - Are consumer choice models good predictive tools?
Do automakers provide the amount of fuel economy that consumers want?

- Fischer suggests that automakers may be operating strategically.
- K&L suggest that:
  - automakers have invested in power instead of fuel economy.
  - a 1% increase in power raises WTP the same as a 1% increase in fuel efficiency.
- Are automakers getting it right?
Taxes vs. Standards

- EPA can’t do much (anything?) on fuel taxes
- EPA doesn’t set fuel economy standards
  - NHTSA does that.
- It’s worth pointing out the opportunity costs
  - But Congress needs to hear about them at least as much as EPA
Recommendations for Future Work

- Consumer, producer tradeoffs between fuel economy and other vehicle attributes
  - How much is fuel economy worth to consumers?
  - How much does it cost automakers?

- Efficiency of markets for fuel economy
  - Do consumers buy the cost-minimizing amount?
  - Do automakers offer the choices that consumers most want?
  - If not, why not?

- The footprint CAFE standard
  - Size may become an important endogenous parameter
Discussion of the Klier-Linn and Fischer papers

In the last couple of years we have seen a remarkable amount of work being completed on new car fuel economy and policies to improve it. In addition to the papers presented at this workshop, we have see work by Jacobson, Gulati and coauthors, Train and Winston, Alcott and Muelleger, Bento and Gould, among others. This work has made use of new and previously unavailable (and still often proprietary) datasets and new methodological approaches. The two papers presented at this workshop are excellent examples of this new body of work. They are very innovative and they reach interesting policy conclusions. They also have another important aspect in common: Each might be summarized by, “And now, a few kind words about CAFE.” Other than that, they are about as different as two papers about CAFE can be.

Klier and Linn

This paper makes at least two significant contributions, I think. First, the authors consider, in greater detail than has been previously the case, the technologies available to improve vehicle fuel economy. To do so, they must have employed an army of research assistants to plow through the old issues of Ward’s Automotive Yearbooks, and because of data limitations they are able to analyze cars, but their analysis of these data is interesting and provocative. As a result, they are able to introduce a new time horizon into the discussion of vehicle fuel-use policies. In addition to the short term, when vehicle characteristics must be taken as given, and the long term, when new technologies can increase the fuel economy of vehicles without sacrificing other characteristics, they define a “medium term,” in which manufacturers can improve fuel economy by changing other vehicle characteristics, in particular by shedding weight or reducing power. Their second contribution is a novel estimation strategy to correct for the problem endogeneity in estimating consumer WTP for various vehicle characteristics. They make use of their detailed engine database to construct new instruments that are highly correlated with those observed characteristics yet uncorrelated with the unobserved characteristics. But rather than go on about how much I like this paper, I think it will be more useful if I raise a couple of questions.

First, in their data engines are classified in a hierarchy. At the top level there are a number of engine platforms, and within each platform are several programs. But the distinction between program and platform—what defines this nesting structure—is never given. We know it has something to do with the level of technology, but it’s not clear what. In particular, what is the relationship, if any, between the hierarchical level and the lead time required by manufacturers to make engine changes? We are told that platform changes are typically not made more than once a decade. Could they be made more often if necessary? Ten years is also time for improvements in technology to be introduced, so would it be correct to say that platform changes overlap between the medium and long term? The authors don’t really say; they just offer a static example. (i.e. the Passat and Audi A4 have the same engine program, and the Jetta has a different program, but all three belong to the same engine platform). I’m not sure how important the distinction is for the paper; the authors don’t really make much of it right away, they just talk about
engines. However, the distinction pops up again in the discussion of the elasticity of substitution between fuel economy and horsepower. They compare models with fixed effects for platform and program and find very different elasticities: -0.06 for fixed program effects and -0.15 for fixed platform effects. They refer to these as “the upper and lower bounds on the medium-term effect of weight and power on fuel efficiency.”

But isn’t this a standard fixed-effects issue, as illustrated in the figure below? When you estimate with platform fixed effects you are failing to observe a lot of heterogeneity across programs, it seems to me. Rather than a contrast between upper and lower bounds, isn’t this just a contrast between two estimating strategies, one of which is more appropriate than the other?

Let me make two other small points:

First, throughout the paper the authors use the term “fuel efficiency” to refer to the outcome of interest, vehicle fuel use per mile. This is what other authors have called “vehicle fuel economy.” I believe engineers use “fuel efficiency” to refer to something else: the amount of useful energy you’re able to get out of the process, relative to the amount you put in. If you get more energy out of the fuel in the tank, you have a choice on how to use it: drive further on the same amount of fuel, increase power, towing capacity, better climate control, etc. The authors say on p. 12 that the “main period” during which fuel efficiency increased was 1975-1984. I think an engineer might say it differently. Definitely, fuel economy improved, with about half that improvement occurring before 1980. But fuel efficiency increased very little in that period before 1980; there just wasn’t time. And in the period after 1985, fuel efficiency improved tremendously, but fuel economy improved very little. In any case, the distinction between fuel efficiency, a technical concept, and fuel economy, a techno-economic concept, is a useful one.

And finally, the authors show pretty convincingly, I think, in the medium term the costs of improving CAFE are lower than the short-term estimates. However, the new cost estimates apply to other policies for improving fuel economy as well, so it’s not clear that the relative cost effectiveness of CAFE has improved.
Fischer

Where the Klier-Linn paper is mostly empirical, Carolyn’s paper is mostly theoretical, with a policy simulation at the end to examine magnitudes. And where Klier and Linn look closely at CAFE costs over time and develop a novel estimation strategy, the main subject in the Fischer paper is market structure. The world auto industry consists of a small number of very large firms, with the predictable effects of oligopoly on prices. As far as I know, Carolyn is the first to point out that oligopolistic distortions can also affect the demand for fuel economy, or indeed any other vehicle attribute. This distortion works to cause manufacturers to oversupply fuel economy for those vehicles appealing to buyers who are likely to value it most, and to undersupply it in vehicle and to undersupply it in vehicles whose customers value it least. The effect is to make fuel taxes, as well as other quasi-market-based instruments involving fleet averaging, less attractive than they might be if market distortions were not considered.

This analysis makes perfect sense to me, and about all I can do at this point is provide a little perspective. I wasn’t sure how large the fuel economy distortion is relative to the fundamental oligopolistic distortion in vehicle prices and whether the former affects the latter. Perhaps the fuel economy distortion in simpler models has been picked up and attributed to price distortion. One would think there is a limit to the total amount of distortion in prices, and it must be distributed among all the discriminatory elements available to the manufacturer.

I’d also like to put in a good word for fuel taxes, which Carolyn finds that gasoline taxes exacerbate “both the incentives for price discrimination and the undervaluation of fuel economy.” Raising fuel prices will certainly increase consumers’ actual valuation of fuel economy, but what I guess she means is that it will increase the proper valuation of it even more. In any case we should remember that CAFE standards only provide fuel conservation incentives in the new vehicle purchase decision. Fuel taxes, by contrast, provide conservation incentives in use: they encourage consumers to drive less; they provide greater incentives for proper vehicle maintenance; they provide incentives for faster fleet turnover (whereas raising CAFE standards probably retards fleet turnover; and above all, raising fuel prices applies these incentives of every vehicle in the fleet.

Let me conclude by commending the authors of both papers for some really creative, interesting and useful work.