DISCUSSION PAPER

December 2010 ■ RFF DP 10-60

Imperfect Competition, Consumer Behavior, and the Provision of Fuel Efficiency in Light-Duty Vehicles

Carolyn Fischer

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

RESOURCES FOR THE FUTURE

Imperfect Competition, Consumer Behavior, and the Provision of Fuel Efficiency in Light-Duty Vehicles

Carolyn Fischer

Abstract

This study explores 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 trade-off emerges. Minimum standards can address distortions from price discrimination but, unlike average standards, do not provide broad-based incentives for improving fuel economy. Increasing fuel prices raises demand for fuel economy but exacerbates undervaluation and incentives for price discrimination. A combination policy may be preferred. For modelers of fuel economy policy, failure to capture consumer heterogeneity in preferences for fuel economy can lead to significant errors in predicting the distribution of effort in complying with regulation, as well as the calculation and distribution of the benefits.

Key Words: fuel economy, regulation, imperfect competition, price discrimination

JEL Classification Numbers: D4, L62, Q5

Contents

Imperfect Competition, Consumer Behavior, and the Provision of Fuel Efficiency in Light-Duty Vehicles

Carolyn Fischer*

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 United States, 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. Reforms include not only strengthening standards but also allowing fuel economy credits to be tradable and adjusting standards according to vehicle characteristics like size.

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. It is well known that market power affects price markups, the distributional effects of regulation, and even the fleet mix, but its effects on the choice of fuel economy have been ignored. We explore the effect 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 roles of market power among automobile manufacturers and heterogeneity among consumers in their preferences for fuel economy. In this situation, a manufacturer has an incentive to choose fuel economy to differentiate its product line, segment consumers, and thus obtain higher prices for its 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 they interact with incentives for price discrimination that may distort the provision of fuel economy in passenger vehicles.

* Fischer is a Senior Fellow at Resources for the Future, 1616 P Street, NW, Washington, D.C. 20036; e-mail: fischer@rff.org. Support from the U.S. Environmental Protection Agency is gratefully acknowledged.

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 forgo purchasing a car altogether.

Empirical studies support this surmise. 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. Luxury car demand is less sensitive to prices and basically insensitive to fuel costs. 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.

Greene (2010) reviews the literature on fuel economy and notes that heterogeneity in consumer tastes poses empirical challenges to inferring the value of vehicle attributes to consumers. More recent studies of consumer preferences for fuel economy acknowledge the difficulty of saying that consumers on average systematically undervalue fuel savings but nevertheless find substantial heterogeneity among consumers in these valuations. Sawhill (2008) finds that "Large portions of the population do appear to either underweight or overweight future operating costs in the automobile purchase decision." Sallee et al. (2010), in evaluating subsamples of the used-car market responses to gas price changes, observe "some intriguing heterogeneity in price adjustment across vehicle classes and makes." For example, they find that Toyota prices are significantly more responsive to gasoline price changes than Ford prices, and that car prices overall adjust more fully than do light-duty truck prices.

Another explanation for different valuations of fuel costs among consumers of different car types is the "mpg illusion," the belief that fuel costs have a linear relationship with miles per gallon (mpg), whereas they are actually proportional to gallons per mile (gpm). Larrick and Soll (2008) have observed this cognitive bias in lab experiments, and Alcott (2010) finds empirical support for it. This illusion implies that consumers of low-fuel economy vehicles underestimate the value of a marginal mpg improvement, while consumers of high-fuel economy vehicles overestimate that value.

Using survey methodology, Kurani and Turrentine (2004) and Turrentine and Kurani (2007) dispute the notion that consumers follow the rational economic framework for computing fuel consumption costs and weighing fuel economy trade-offs. 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."[1]

At the same time, there is certainly empirical support for the presence of market power in the automobile industry: according to the 2002 Economic Census,[2] the largest four firms accounted for 75.5 percent of the value of shipments in the automobile market and 95.7 percent of the light-duty and utility vehicle market, and the Herfindahl Hirschman Index for light vehicles overall is 2600; above 1800 is the Justice Department's definition of a "highly concentrated" industry.

Table 1. U.S. Market Shares for Light-Duty Vehicles, Model Year 2008

Manufacturer	*Market share (percentage)*
General Motors	23
Ford	16
Toyota	16
Chrysler	12
Honda	11
Nissan	7
All other	15

Table 1 gives the market shares of light-duty vehicle sales, according to the National Highway Traffic Safety Administration, for the model year 2008. Furthermore, empirical evidence of brand loyalty (Train and Winston 2007) 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.

[1] Kurani and Turrentine (2004, III).

[2] Concentration ratio data are not yet available for the 2007 Economic Census.

However, modelers of automobile markets and their regulation have largely ignored the effects of consumer heterogeneity on the strategies of vehicle manufacturers for improving fuel 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 2010; Bento et al. 2005, 2009; Berry et al. 1995; Goldberg 1995, 1998; Kwoka 1983; Petrin 2002). Although this assumption is useful for modeling short-run responses to policy or gas price changes, studies based on it 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 have not addressed the strategic problem because they asssumed perfect competition or aggregated 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, although they do evaluate the effect 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. Because of 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 are 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 overprovided 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, a manufacturer can charge higher prices to small-car consumers without worrying they will switch classes. Similarly, it can charge higher prices for large cars when it is 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 determining whether they can enhance welfare as well as fuel economy. We complement the analytical work with simple numerical simulations to indicate 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 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 ϕ_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 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 ($\partial C_i / \partial \phi_i < 0$ and $\partial^2 C_i / \partial \phi_i^2 > 0$). Consumer demand for class *i* is a function of the vector of prices and fuel consumption rates for all vehicles ($q_i(\mathbf{P}, \boldsymbol{\varphi})$). 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:

$$V(\mathbf{P}, \boldsymbol{\varphi}) = \sum_i (P_i - C_i(\phi_i)) q_i(\mathbf{P}, \boldsymbol{\varphi}) \tag{1}$$

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

$$\frac{\partial V(\mathbf{P}, \boldsymbol{\varphi})}{\partial P_i} = q_i + \sum_j \pi_j \frac{\partial q_j}{\partial P_i} = 0 \tag{2}$$

where $\pi_j = P_j - C_j(\phi_j)$ is the own marginal profit (or total markup) for vehicle type *j*. Let $\eta_{ji} = \frac{\partial q_j}{\partial P_i}\frac{P_i}{q_j}$ 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

$$P_i = \sum_j \pi_j(-\eta_{ji})\frac{q_j}{q_i} \tag{3}$$

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:

$$P_i = C_i(\phi_i)\frac{\eta_{ii}}{\eta_{ii}+1} + \sum_{j\neq i}\pi_j \frac{-\eta_{ji}}{(\eta_{ii}+1)}\frac{q_j}{q_i} \tag{4}$$

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 percent 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 percent in equilibrium. In the perfectly competitive case, as $\eta_{ii} \to -\infty$ the firm becomes a price taker, and we get a 100 percent pass-through of cost changes into retail prices. However, most empirical studies have found positive markups, validating models of oligopolistic competition.[3]

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

$$\frac{\partial V(\mathbf{P},\boldsymbol{\varphi})}{\partial \phi_i} = -\frac{\partial C_i(\phi_i)}{\partial \phi_i}q_i + \sum_j \pi_j \frac{\partial q_j}{\partial \phi_i} = 0 \tag{5}$$

[3] Bresnahan (1981) and Feenstra and Levinsohn (1995) found markups in the range of 4 to 25 percent for individual models. An NRC (2002) study assumed a 40 percent markup for cost increases, shared across parts and auto manufacturers and retailers. This and subsequent studies use published dealer markups and the estimated ratio of dealer and manufacturer markups from Bresnahan and Reiss (1986). Bento et al. (2009) find markups in the range of 14 to 46 percent.

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

$$-\frac{\partial C_i(\phi_i)}{\partial \phi_i} = \frac{\sum_j \pi_j \frac{\partial q_j}{\partial \phi_i}}{\sum_j \pi_j \frac{\partial q_j}{\partial P_i}} \tag{6}$$

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 vehicle miles traveled, discounting, and preferences). Efficiency, at least in allocating fuel economy, would require that $-\frac{\partial C_i(\phi_i)}{\partial \phi_i} = g\bar{\rho}_i$, meaning the per vehicle cost increase equals that average willingness to pay for lower fuel consumption.

With Bertrand pricing, this condition holds if $\sum_{j \neq i} \pi_j \frac{\partial q_j}{\partial \phi_i} = g\bar{\rho}_i \sum_{j \neq i} \pi_j \frac{\partial q_j}{\partial P_i}$. 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* (i.e., 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 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 ($\bar{\rho}_i = \bar{\rho}$ 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 as they do to 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, 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 changes in the fuel consumption rate; that is, a change in perceived fuel costs has the same effect on demand as a change in the price of a vehicle. However, those perceived fuel costs may differ by vehicle type, not only because of differences in average fuel consumption rates but also because of different average valuations of the fuel consumption rate. For example, let the perceived cost to the average consumer of vehicle type *j* for driving vehicle *i* be $g\bar{\rho}_j\phi_i$. If we assume $\frac{\partial q_j}{\partial\{g\bar{\rho}_j\phi_i\}} = \frac{\partial q_j}{\partial P_i}$, then $\frac{\partial q_j}{\partial \phi_i} = g\bar{\rho}_j \frac{\partial q_j}{\partial P_i}$. Furthermore, $\frac{\partial q_j}{\partial P_i} = \frac{\eta_{ji} q_j}{P_i}$. Substituting, we get

$$-\frac{\partial C_i(\phi_i)}{\partial \phi_i} = g\left(\bar{\rho}_i + \frac{\sum_j (\bar{\rho}_i - \bar{\rho}_j)\pi_j \eta_{ji} q_j}{-\sum_j \pi_j \eta_{ji} q_j}\right) \tag{7}$$

(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 overprovided 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, a manufacturer can charge higher prices to small-car consumers without worrying they will switch classes. Similarly, it can charge higher prices for large cars when it is 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 from price discrimination incentives. We find that most either do little or exacerbate the distortions, 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, $\Sigma_i \phi_i q_i \leq \bar{\phi}\, \Sigma_i q_i$.[4] 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

$$L = V(\mathbf{P}, \boldsymbol{\varphi}) - \lambda \sum_i (\phi_i - \bar{\phi}) q_i(\mathbf{P}, \boldsymbol{\varphi}) \tag{8}$$

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.)

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

Let $\hat{\pi}_j = P_j - C_j(\phi_j) - \lambda(\phi_j - \bar{\phi})$. Rearranging, as in Equation (4), we can express the price as the sum of the vehicle's 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-

[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 applicable standard. Vehicles weighing more than 8,500 pounds (such as the Hummer H2 and Ford Excursion) are exempt from CAFE.

price responses, weighted by the marginal profits of the other vehicles in the manufacturer's fleet:

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

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 or subsidy.

The first-order conditions with respect to fuel economy are

$$\frac{\partial L(\mathbf{P}, \boldsymbol{\varphi})}{\partial \phi_i} = \left(-\frac{\partial C_i(\phi_i)}{\partial \phi_i} - \lambda\right) q_i + \sum_j \hat{\pi}_j \frac{\partial q_j}{\partial \phi_i} = 0 \tag{11}$$

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

$$-\frac{\partial C_i(\phi_i)}{\partial \phi_i} = \frac{\sum_j \hat{\pi}_j \frac{\partial q_j}{\partial \phi_i}}{\sum_j \hat{\pi}_j \frac{\partial q_j}{\partial P_i}} + \lambda \tag{12}$$

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:

$$-\frac{\partial C_i(\phi_i)}{\partial \phi_i} = g\left(\bar{\rho}_i + \frac{\sum_j (\bar{\rho}_i - \bar{\rho}_j)\left(\pi_j - \lambda(\phi_j - \bar{\phi})\right)\eta_{ji} q_j}{-\sum_j \left(\pi_j - \lambda(\phi_j - \bar{\phi})\right)\eta_{ji} q_j}\right) + \lambda \tag{13}$$

In the absence of CAFE, vehicles with higher-than-average consumer willingness to pay for fuel economy generally 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 the fuel economy component of 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, $\Sigma_i \phi_i q_i \leq \Sigma_i \bar{\phi}_i q_i$. Sized-based standards can improve overall cost-effectiveness over uniform standards if manufacturers are sufficiently heterogeneous and cannot trade credits, since 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

$$L = V(\mathbf{P}, \boldsymbol{\varphi}) - \lambda \sum_i (\phi_i - \bar{\phi}_i) q_i(\mathbf{P}, \boldsymbol{\varphi}) \tag{14}$$

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

$$P_i = \left(C_i(\phi_i) + \lambda(\phi_i - \bar{\phi}_j)\right) \frac{\eta_{ii}}{(\eta_{ii} + 1)} + \sum_{j \neq i} \tilde{\pi}_i \frac{-\eta_{ji}}{(\eta_{ii} + 1)} \frac{q_j}{q_i} \tag{15}$$

where $\tilde{\pi}_j = P_j - C_j(\phi_j) - \lambda(\phi_j - \bar{\phi}_j)$. 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

$$-\frac{\partial C_i(\phi_i)}{\partial \phi_i} = g\left(\bar{\rho}_i + \frac{\sum_j (\bar{\rho}_i - \bar{\rho}_j)\left(\pi_j - \lambda(\phi_j - \bar{\phi}_j)\right)\eta_{ji} q_j}{-\sum_j \left(\pi_j - \lambda(\phi_j - \bar{\phi}_j)\right)\eta_{ji} q_j}\right) + \lambda \tag{16}$$

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, which 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 effect 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

$$L = V(\mathbf{P}, \boldsymbol{\varphi}) - \sum_i \lambda_i (\phi_i - \bar{\phi}_i) q_i \tag{17}$$

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 profits: $\pi_j = P_j - C_j(\phi_j)$, since $\lambda_i(\phi_i - \bar{\phi}_i) = 0$. In other words, this regulation does not create an incentive for fleet-mix shifting via pricing (other than by changes in actual costs).

[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.

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.

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

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 ($\bar{\rho}$ and $\bar{\phi}$) and differences (Δ_ρ and Δ_ϕ):

$$\bar{\rho}_S = \bar{\rho} + \Delta_\rho, \quad \bar{\rho}_L = \left(\bar{\rho}(1 - q_S) - q_S \Delta_\rho\right) / q_L$$
$$\phi_S = \bar{\phi} - \Delta_\phi, \quad \phi_L = \left(\bar{\phi}(1 - q_S) - q_S \Delta_\phi\right) / q_L$$

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 ϕ_i—and the average consumer willingness to pay in a given class. In the absence of regulation ("NR"), this simplifies to

$$MRB_L^{NR} - g\bar{\rho}_L = -\frac{g m_S \eta_{SL} q_S \Delta_\rho}{\chi_L},$$
$$MRB_S^{NR} - g\bar{\rho}_S = \frac{g B m_L \eta_{LS} \Delta_\rho}{\chi_S}$$

where $\chi_L = \left(-\eta_{LL} B m_L (1 - q_S) - m_S \eta_{SL} q_S\right)(1 - q_S)$ and $\chi_S = \left(-\eta_{SS} m_S q_S - B m_L \eta_{LS} (1 - q_S)\right)$.

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

$$MRB_L^U - MRB_L^{NR} = \lambda - g\frac{\lambda}{P_S}\left(\frac{q_S\eta_{SL}\Delta_\rho\Delta_\phi}{\chi_L}\right)$$
$$MRB_S^U - MRB_L^{NR} = \lambda - g\frac{\lambda}{P_S}\left(\frac{q_S\eta_{LS}\Delta_\rho\Delta_\phi}{(1-q_S)\chi_S}\right)$$

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.

$$MRB_L^{SBS} - MRB_L^{NR} = \lambda - g\frac{\lambda}{P_S}\left(\frac{q_S\eta_{SL}\Delta_\rho(\Delta_\phi - \Delta_{\bar{\phi}})}{\chi_L}\right)$$
$$MRB_S^{SBS} - MRB_L^{NR} = \lambda - g\frac{\lambda}{P_S}\left(\frac{q_S\eta_{LS}\Delta_\rho(\Delta_\phi - \Delta_{\bar{\phi}})}{(1-q_S)\chi_S}\right)$$

where $\Delta_{\bar{\phi}} = \bar{\phi} - \bar{\phi}_S$ 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 Ward's (2007), for the 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 percent of the national automobile fleet. We draw on the recent study by Bento et al. (2009, Table A-1) to calibrate marginal profits. With their markups by manufacturers, we calculate average sales-weighted markups for compact cars of roughly 22 percent, and markups for mid- and full-sized cars average 25 percent.

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 (2004) and Jacobsen (2010) (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,

$$\eta_{LL} = -\frac{B(1-q_S) + \eta_{LS} m_S q_S}{B m_S (1-q_S)}, \quad \eta_{SS} = -\frac{B \eta_{LS} m_L (1-q_S) + q_S}{m_S q_S}$$

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

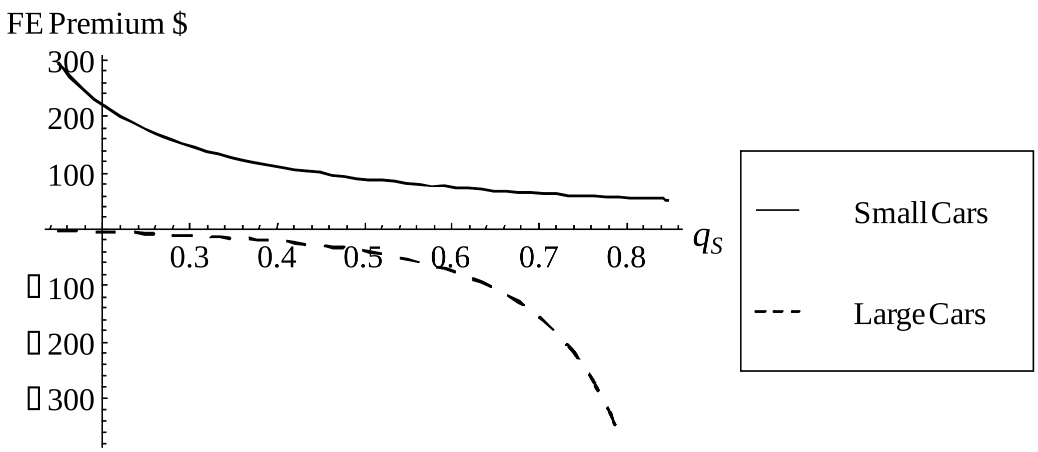
$$MRB_L^{NR} - g\,\bar{\rho}_L = -0.075\Delta_\rho, \quad MRB_S^{NR} - g\,\bar{\rho}_S = 0.180\Delta_\rho$$

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 percent of that amount for small cars. Meanwhile, it decreases the MRB for large cars by 8 percent 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. For example, although Honda and GM have a roughly even split in their car fleets, small cars represent one-third of Toyota and Ford car fleets but roughly three-quarters of the car fleets of European and other Asian manufacturers (Ward's 2007). 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).[6] 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.

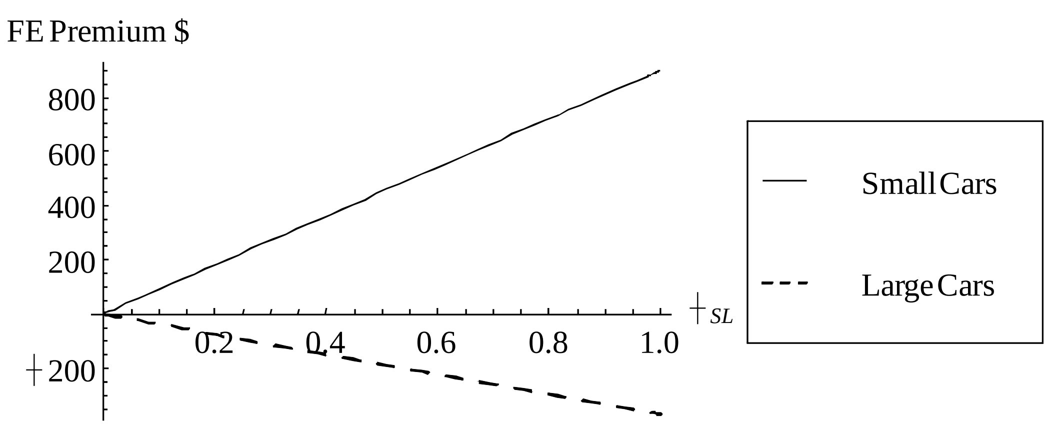
[6] The figures assume Δ_ρ =500.

Figure 1. Sensitivity of Fuel Economy Premium to Fleet Share of Small Cars



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 Fuel Economy Premium to Cross-Price Elasticities of Small and Large Cars



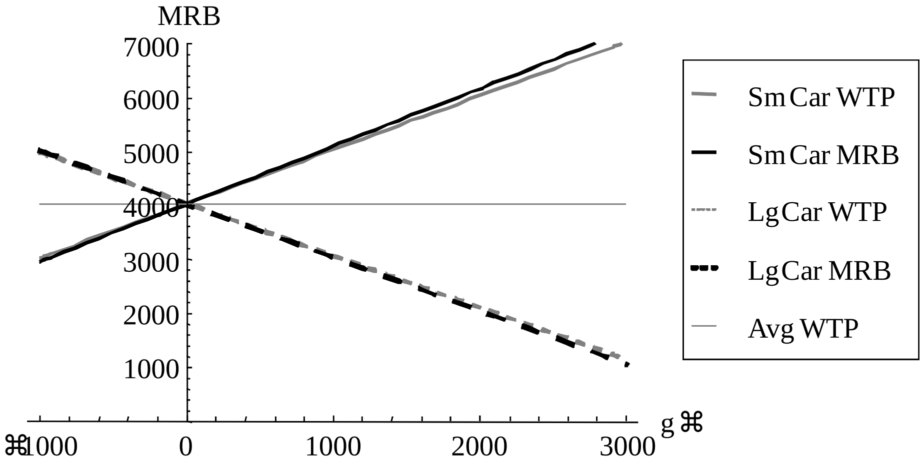
On the other hand, the distortions get smaller as the own-price elasticities get larger; this result is evident from the previous equations, since the χ s (the denominators) increase with the own-price elasticities.

The additional distortion from CAFE standards appears to be relatively small. Assuming a rather substantial shadow value of λ =\$2000, and a $\Delta_{\phi} = .3$ from the baseline data, we find that $MRB_L - g\bar{\rho}_L = \lambda - 0.084\Delta_{\rho}, \quad MRB_S - g\bar{\rho}_S = \lambda + 0.166\Delta_{\rho}$. 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 with the absence of such a distortion.

Finally, it is worth considering the effect of Δ_{ρ} 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 National Academy of Sciences study assumptions of annual travel (15,600 miles in the first year, declining by 4.5 percent annually), vehicle lifetime (14 years), discount rate (5 percent), and on-road shortfall (15 percent), this translates into a willingness to pay for a farsighted consumer of \$1,491 per \$1 of gasoline price (or about \$4,000 at our assumed price of \$2.70).[7] 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.

[7] Thus, our earlier assumptions in the figures of Δ_{ρ} =500 imply that small-car consumers are willing to pay about twice as much per \$1 of gasoline price as large-car consumers.

Figure 3. Influence of Disparity in Willingness 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 overprovide fuel economy in vehicle 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 trade-off 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.

A logical extension of this research is to incorporate the effects of market power on fuel economy choice in a more detailed model of the U.S. auto market with multiple manufacturers and vehicle classes. Given the full interdependency of strategic pricing and fuel economy decisions across models and manufacturers, 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 product markets, 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.[8] Still, few empirical studies consider such complexities in consumer response to fuel costs. Finally, although some policy simulation models do include imperfect competition, most do not capture heterogeneity in consumer willingness to pay for fuel economy (as distinct from price responses), and future research is needed to understand how this may influence predictions of the costs and distributional effects of fuel economy policy.

[8] See Fischer et al. (2007).

References

Alcott, H. 2010. Beliefs and Consumer Choice. MIT, NYU, and ideas42 manuscript. November 29 version.

Austin, D., and T. Dinan. 2005. Clearing the Air: The Costs and Consequences of Higher CAFE Standards and Increased Gasoline Taxes. *Journal of Environmental Economics and Management* 50: 562–82.

Bento, A., L.H. Goulder, E. Henry, M.R. Jacobsen, and R.H. von Haefen. 2005. Distributional and Efficiency Impacts of Gasoline Taxes: An Econometrically Based Multi-market Study. *American Economic Review* 95(2): 282–87.

Bento, A.M., L.H. Goulder, M.R. Jacobsen, and R.H. von Haefen. 2009. "Distributional and Efficiency Impacts of Increased US Gasoline Taxes." *American Economic Review*, 99(3): 667–99.

Berry, S., J. Levinsohn, and A. Pakes. 1995. Automobile Prices in Market Equilibrium. *Econometrica* 63(4): 841–90.

Bresnahan, T. 1981. Departures from Marginal-Cost Pricing in the American Automobile Industry: Estimates for 1977–1978. *Journal of Econometrics* 17, 201–27.

Bresnahan, T.F., and P. Reiss. 1986. Departures from Marginal-Cost Pricing in the American Automobile Industry: Estimates for 1977–1978. *Journal of Econometrics* 11: 201–27.

Elmer, K.F., and C. Fischer. 2009. Designing Vehicle CO2 Emission Standards: Uniform vs. Weight-Based Standards. Working paper. Washington, DC: Resources for the Future.

Feenstra, R., and J. Levinsohn. 1995. Estimating Markups and Market Conduct with Multi-Dimensional Product Attributes. *Review of Economic Studies* 62: 19–52.

Fischer, C. 2005. On the Importance of the Supply Side in Demand-Side Management. *Energy Economics*, 27 (1): 165–180.

Fischer, C., I. Parry, and W. Harrington. 2005. Economic Impacts of Tightening the Corporate Average Fuel Economy (CAFE) Standards. Report prepared for Environmental Protection Agency and National Highway Traffic Safety Administration.

Fischer, C., W. Harrington, and I.W.H. Parry. 2007. Do Market Failures Justify Tightening Corporate Average Fuel Economy (CAFE) Standards? *Energy Journal* 28(4): 1–30.

Goldberg, P.K. 1995. Product Differentiation and Oligopoly in International Markets: The Case of the US Automobile Industry. *Econometrica* 63: 891–951.

———. 1998. The Effects of the Corporate Average Fuel Efficiency Standards in the US. *Journal of Industrial Economics* 46: 1–33.

Greene, D.L. 1996. *Transportation and Energy*. Washington, DC: Eno Transportation Foundation, Inc.

———. 2002. Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards. Report of the Committee, National Research Council. Washington, DC: National Academy Press.

———. 2010. How Consumers Value Fuel Economy: A Literature Review. Technical Report EPA-420-R-10-008. Washington, DC: Assessment and Standards Division Office of Transportation and Air Quality, U.S. Environmental Protection Agency. March.

Greene, D.L., P.D. Patterson, M. Sing, and J. Li. 2005. Feebates, Rebates and Gas-Guzzler Taxes: A Study of Incentives for Increased Fuel Economy. *Energy Policy* 33(6): 721–827.

Jacobsen, M.R. 2010. Evaluating U.S. Fuel Economy Standards In a Model with Producer and Household Heterogeneity. Manuscript. Department of Economics, University of California–San Diego.

Kleit, A.N. 2004. Impacts of Long-Range Increases in the Corporate Average Fuel Economy (CAFE) Standard. *Economic Inquiry* 42: 279–94.

Kurani, K.S., and T. Turrentine. 2004. Analysis of Consumer Response to Automobile Regulation and Technological Change in Support of California Climate Change Rulemaking. Final Report, prepared for the California Air Resources Board and California Environmental Protection Agency. Institute for Transportation Studies, University of California–Davis.

Kwoka, J.E., Jr. 1983. The Limits of Market-Oriented Regulatory Techniques: The Case of Automotive Fuel Economy. *Quarterly Journal of Economics* November: 695–704.

Larrick, R., and J. Soll. 2008. The MPG Illusion. *Science* 320 (5883): 1593–94.

National Research Council (NRC). 2002. *Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards*. Washington, DC: National Academy Press.

Petrin, A. 2002. Quantifying the Benefits of New Products: The Case of the Minivan. *Journal of Political Economy* 110: 705–29.

Plourde, C., and V. Bardis. 1999. Fuel Economy Standards in a Model of Automobile Quality. *Energy Economics* 21: 309–19.

Rubin, J., P. Leiby, and D. Greene. 2009. Tradable Fuel Economy Credits: Competition and Oligopoly. Journal of Environmental Economics and Management 58 (3): 315–328

Sallee, J.M., S.E. West, and W. Fan. 2010. The Effect of Gasoline Prices on the Demand for Fuel Economy in Used Vehicles: Empirical Evidence and Policy Implications. Manuscript, Department of Economics, Macalester College. (June 18, 2010 version).

Sawhill, J. 2008. Are Capital and Operating Costs Weighted Equally in Durable Goods Purchases? Evidence from the US Automobile Market. Manuscript. Haas School of Business, University of California–Berkeley.

Train, K.E., and C. Winston, 2007. Vehicle Choice Behavior and the Declining Market Share of U.S. Automakers. *International Economic Review* 48(4): 1469–96.

Turrentine, T.S., and K.S. Kurani. 2007. Car Buyers and Fuel Economy. *Energy Policy* 35: 1213–23.

Ward's Automotive Yearbook. 2007. 69th Edition.