

# Using Loopholes to Reveal the Marginal Cost of Regulation: The Case of Fuel-Economy Standards\*

Preliminary and incomplete. Please do not cite or quote.

Soren T. Anderson<sup>†</sup>  
Michigan State University

James M. Sallee<sup>‡</sup>  
University of Chicago

October 15, 2008

---

\*For helpful comments and suggestions we thank Lucas Davis, Meredith Fowlie, Ben Keys, Brian Cadena, Brian Kovak, Alex Resch, Stephen Salant, and Gary Solon. We thank Alan Berkowitz and Peter Feather for providing historical fuel-economy data and for answering numerous questions about CAFE standards. We thank Wei Fan for significant help with the vehicle transaction data. All errors are our own.

<sup>†</sup>Address: Soren T. Anderson, Department of Economics and Department of Agricultural, Food, and Resource Economics, Michigan State University. Phone: 517-355-0268. Email: [sta@msu.edu](mailto:sta@msu.edu). Web address: <http://www.msu.edu/~sta>. Anderson gratefully acknowledges financial support from the U.S. Environmental Protection Agency (EPA) under the Science to Achieve Results (STAR) Graduate Fellowship Program. EPA has not officially endorsed this publication and the views expressed herein may not reflect the views of the EPA.

<sup>‡</sup>Address: James M. Sallee, The Harris School, University of Chicago. Phone: 773-316-3480. Email: [sallee@uchicago.edu](mailto:sallee@uchicago.edu). Web address: <http://home.chicago.edu/~sallee>

## Abstract

Corporate Average Fuel Economy (CAFE) regulations constrain automakers to produce vehicles whose average efficiency exceeds a minimum standard. A “loophole” in the program allows firms to relax this constraint by producing gasoline-ethanol flexible-fuel vehicles, which are credited with far better mileage than they actually achieve. In this paper, we demonstrate that when firms use this loophole, they reveal the marginal cost of complying with the standard. This is because firms equate the marginal cost of relaxing the constraint via the loophole with the marginal cost of complying through other means, such as selling smaller vehicles or installing fuel-saving technologies. We show that under certain conditions the marginal cost of relaxing the constraint via the loophole is a simple function of readily available parameters. We demonstrate empirically that these sufficient conditions hold in recent years for major U.S. automakers. We calculate that the cost of increasing CAFE standards by one mile per gallon is between \$8 and \$28 in lost profit per vehicle for domestic automakers. These costs are far lower than the non-compliance penalty of \$55, which has been used as a cost parameter in previous research. More generally, the methodology we develop here may be able to reveal the marginal cost of compliance with other regulations whose costs are otherwise difficult to determine.

JEL classification numbers: L5, Q5

Key words: CAFE, fuel-economy standards, automobile prices, cost of regulation, ethanol, alternative fuels

# 1 Introduction

Estimating the cost of regulation is difficult. Few regulations allow trading that could reveal compliance costs through transaction prices, and regulated firms rarely have an incentive to report costs truthfully. Some regulations, however, feature “loopholes” that allow firms to relax regulatory constraints. When the cost of using a loophole is known, researchers can infer the marginal cost of regulation indirectly for firms that exploit the loophole. We demonstrate that firms in the auto industry reveal the marginal cost of complying with fuel-economy standards when they exploit a loophole that overstates the efficiency of “flexible-fuel” vehicles. Using this approach, we estimate that tightening fuel-economy standards by one mile per gallon would cost domestic automakers between \$8 and \$28 in profit per vehicle, which is consistent with other recent attempts to measure these costs directly (Jacobson 2008). Our cost estimates are far lower than the statutory fine of \$55 for non-compliance, which other researchers have used as a measure of marginal compliance costs, even though domestic automakers do not pay fines (Goldberg 1998; Rubin and Leiby 2000; Austin and Dinan 2005; Liu and Helfand 2008).

Corporate Average Fuel Economy (CAFE) standards require automakers to achieve a minimum average mileage across their entire vehicle fleet. Firms whose fleet average falls below the minimum are subject to a fine. The Alternative Motor Fuels Act (AMFA) modified CAFE regulations starting in 1993 by crediting vehicles capable of burning gasoline and ethanol with about two-thirds better mileage than they actually achieve. These vehicles are known as “flexible-fuel” vehicles.<sup>1</sup> Automakers can make any conventional vehicle a flexible-fuel vehicle through a minor modification, which adds only \$100–\$200 in production cost, as we discuss in detail below. If consumers fill their tanks with gasoline instead of ethanol, a flexible-fuel vehicle is virtually identical to its gasoline counterpart, with negligible differences in performance. Thus, automakers can improve their average mileage under CAFE

---

<sup>1</sup>Flexible-fuel vehicles actually run on a fuel blend known as “E85,” which contains 85% pure ethanol and 15% gasoline. We refer to this fuel as “ethanol” throughout.

regulations by fitting existing models with flexible-fuel capacity, even though this has little to no impact on the true mileage that drivers obtain. Flexible-fuel production is therefore a substitute for other compliance strategies, such as modifying vehicles to be more efficient or selling a larger fraction of small vehicles. The basic insight of this paper is that a profit-maximizing firm will equate the marginal costs of different compliance strategies. Thus, we can use the cost of compliance using flexible-fuel vehicles, which is readily observable, to estimate the cost of compliance by other means, which is not otherwise observable.

We begin by modeling the profit-maximization decision of an oligopolistic automaker. The automaker faces a fuel-economy constraint but can relax the constraint, up to a point, by producing flexible-fuel vehicles. The model provides sufficient conditions under which we can infer the marginal cost of tightening CAFE standards by examining the cost of exploiting the flexible-fuel loophole. If an automaker (1) is constrained by CAFE standards, (2) has installed flexible-fuel capacity on some but not all units for some model, and (3) has not exhausted the maximum gain in fuel economy from producing flexible-fuel vehicles, and if (4) marginal consumers do not value flexible-fuel capacity, then the automaker will equate the marginal cost of improving mileage using the flexible-fuel loophole with the marginal cost of improving mileage through other means.

The empirical portion of the paper demonstrates that these conditions hold for domestic automakers. Using administrative data from the Department of Transportation, we show that domestic automakers were constrained by CAFE standards and used flexible-fuel vehicles to comply with the regulations. Domestic automakers rarely added flexible-fuel capacity to more than one type of vehicle, and unconstrained Asian automakers did not produce any flexible-fuel vehicles. Automakers that produced flexible-fuel vehicles installed flexible-fuel capacity on some but not all units, and automakers almost never exceeded the maximum gain in fuel economy permitted under the provision.

Next, we show that marginal consumers do not value flexible-fuel capacity, using transaction data to analyze both prices and quantities. Automakers sell a large portion of their

flexible-fuel vehicles to consumers living in states with virtually no ethanol fueling stations. Consumers in these states are almost certainly not willing to pay more for flexible-fuel vehicles, since they are not able to purchase ethanol. Furthermore, our analysis of transaction prices for flexible-fuel vehicles and comparable gasoline-only vehicles indicates that consumers do not pay more for flexible-fuel capacity, which is consistent with survey evidence that many flexible-fuel owners do not know they own flexible-fuel vehicles.

Because marginal consumers do not value flexible-fuel capacity, and because domestic automakers have exploited the flexible-fuel loophole without exhausting it, the flexible-fuel provision reveals the cost of marginally increasing CAFE standards. The cost of CAFE is a function of vehicle fuel economy and the cost of adding flexible-fuel capacity. Incremental production costs for flexible-fuel vehicles reportedly range from \$100–\$200 or lower. For automakers that produce flexible-fuel vehicles to comply with CAFE standards, this range implies that the marginal cost of tightening the standard for light trucks by one mile per gallon is \$11–\$28 in lost profit per vehicle. The cost of tightening the standard for passenger cars is \$8–\$18. Because the automaker equates the marginal costs of alternative compliance strategies, our cost estimates also reflect lower profit margins on smaller, more efficient vehicles, as well as the gap between incremental production costs and willingness to pay for fuel-saving modifications.

Our estimate of the marginal cost of tightening CAFE standards is almost identical to recent estimates by Jacobson (2008), who uses a wholly different methodology. Jacobson measures compliance costs by directly estimating demand elasticities and implied marginal costs. We find the similarity of his and our results reassuring. These costs are far lower than the \$55 fine that automakers would pay if they failed to comply with CAFE standards, which should serve as a plausible upper bound on marginal compliance costs. Previous research has used the \$55 fine as a measure of cost (e.g., Goldberg and others). Moreover, some researchers have suggested that true costs may exceed \$55 because automakers fear that violating CAFE standards would hurt their image or expose them to costly litigation (Kleit

2004; Austin and Dinan 2005). Our estimates are at odds with these industry-driven claims. Future analysis of CAFE could be improved by using our estimates of marginal cost, rather than the \$55 fine.

More broadly, our approach can inform research measuring the cost of regulation in other industries. A prominent example is “incentive zoning.” Zoning regulations typically constrain the height and density of new buildings in a jurisdiction. Under incentive zoning, these constraints are relaxed if developers provide open space, affordable housing, or other public goods.<sup>2</sup> Following our methodology, researchers could estimate the marginal benefit to developers of easing height or density restrictions by quantifying how much developers spend on plazas or affordable housing to avoid these restrictions.

Our analysis of the flexible-fuel vehicle market also contributes to the policy debate and growing literature on alternative fuels policies. The original rationale for the flexible-fuel provision was to solve a classic coordination problem. Without vehicles that ran on ethanol, it was thought, retailers would have no incentive to install new fuel pumps for distributing ethanol. Without pumps, consumers would never demand vehicles that burn the fuel. Policymakers hoped that the flexible-fuel provision would solve this coordination problem. By inducing automakers to make flexible-fuel vehicles through a CAFE credit, the provision would put alternative-fuel vehicles on the road, and infrastructure would follow. In reality, ethanol infrastructure has not kept pace with flexible-fuel production, and few flexible-fuel vehicles ever run on ethanol.<sup>3</sup> Theoretical research suggests that AMFA therefore increases gasoline consumption and greenhouse gas emissions by weakening CAFE standards (Liu and Helfand 2008). Our empirical analysis showing that automakers allocate most flexible-fuel vehicles to locations without ethanol supports this conclusion. These findings bolster arguments that the flexible-fuel provision has not achieved its goals (National Academy of

---

<sup>2</sup>Incentive zoning began in Chicago and New York City, where developers were allowed to exceed height and density restrictions if they provided plaza space (Weiss 1992; Morris 2000). At least half of all cities and towns with zoning laws reportedly have some incentive zoning program (Morris 2000).

<sup>3</sup>Anderson (2008) shows that demand for ethanol does exist. Since supply is scarce in all but a few locations, however, few flexible-fuel vehicle owners have access to the fuel.

Sciences 2002).

The remainder of this paper is organized follows. Section 2 models an automaker’s decision to use the flexible-fuel loophole to relax fuel-economy constraints and establishes sufficient conditions under which we can infer marginal compliance costs. The next several sections demonstrate that these conditions hold empirically. Section 3 shows that domestic automakers use flexible-fuel vehicles to comply with CAFE standards, that they install flexible-fuel capacity on some but not all units, and that they have not exhausted the flexible-fuel loophole. Section 3 also shows that the set of vehicles we observe with flexible-fuel capacity is broadly consistent with our model’s predictions. Section 4 argues that marginal consumers do not value flexible-fuel capacity. Section 5 then uses publicly reported estimates for the incremental cost of producing a flexible-fuel vehicle to calculate the marginal cost of complying with fuel-economy standards. Section 6 briefly discusses what the results imply about the CAFE program’s net social benefits, and section 7 concludes.

## **2 Revealing the cost of fuel-economy standards**

We model an automaker as maximizing profits in an oligopolistic framework, subject to the constraints of Corporate Average Fuel Economy regulations. We require a fair bit of notation to portray the market structure and policy, but the bottom line is simple. An automaker faces a policy constraint, which it can relax by increasing the share of flexible-fuel vehicles. The first-order condition characterizing optimal flexible-fuel shares yields an equation that defines the shadow price of the constraint in terms of observable quantities. This first-order condition is independent of demand elasticities and markups, which are specific to the structure of the pricing equilibrium. The loophole methodology therefore allows us to estimate the shadow price on the constraint while remaining agnostic about the details of the oligopolistic equilibrium and key parameters that we do not observe.

## 2.1 Market structure

We assume that an oligopolistic automaker complying with fuel-economy standards maximizes profits with respect to the prices, mileage, and flexible-fuel shares of the models it produces:

$$\max_{p, \theta} \pi = \sum_{j \in \mathcal{M}} \left( p_j - c_j(m_j) - \alpha_j \theta_j \right) q_j(p, m) - \sum_{j \in \mathcal{M}} I(\theta_j > 0) \cdot F_j \quad (1)$$

where:  $\mathcal{M}$  is the set of models the automaker produces;  $p_j$  is the price the automaker charges for model  $j$ ;  $m_j$  is the model’s fuel economy in miles per gallon;  $q_j$  is its sales quantity, which depends on the prices  $p$  and mileage  $m$  for all models of all producers;  $c_j$  is the constant marginal cost of the gasoline-only version of the model, which depends on the model’s mileage;  $\theta_j \in [0, 1]$  is the model’s flexible-fuel share, or the fraction of units with flexible-fuel capacity;  $\alpha_j$  is the incremental production cost of outfitting one such unit with flexible-fuel capacity; and  $F_j$  is the fixed cost of engineering the model to have flexible-fuel capacity, which the automaker pays if the model’s flexible-fuel share exceeds zero, as denoted by the indicator function  $I(\theta_j > 0)$ . Profits equal the sum over all models of price minus average variable cost multiplied by quantity, minus engineering fixed costs. We assume that the set of models is fixed.

Fitting a vehicle with flexible-fuel capacity entails both variable and fixed costs. In addition to having larger fuel injectors, flexible-fuel vehicles have fuel-system components made from materials that are more resistant to the corrosive nature of ethanol. Earlier models also had special fuel sensors to detect the percent ethanol content of fuel running through the engine. Incremental costs vary from model to model, depending on a model’s engine technology and sales volume.<sup>4</sup> Often more important than the hardware changes themselves, however, is the engineering time and effort needed to add flexible-fuel capacity. Outfitting a new model with flexible-fuel capacity requires making minor design changes, modifying on-board software, doing additional engine calibration work, and performing extra

---

<sup>4</sup>If a model has a large sales volume, there are likely to be multiple suppliers of parts. Incremental flexible-fuel costs can be lower for such models, as parts suppliers compete to sell flexible-fuel components.

emissions testing. These up-front fixed costs can be substantial.

In equation (1) we specify a separate fixed cost for each model. In reality, different models often share the same engines, implying substantial overlap in fixed costs. Thus, when we analyze actual flexible-fuel production below, we focus on flexible-fuel shares for specific engine sizes, which proxy for models with shared fixed costs.

Our model implicitly assumes that consumers do not care about flexible-fuel capacity one way or the other. Quantities do not depend on flexible-fuel shares, which implies, for example, that no consumer would switch from a Honda Accord to a Chevy Impala if General Motors increased the fraction of Impalas with flexible-fuel capacity. Similarly, we do not include separate prices for flexible-fuel vehicles and their gasoline-only counterparts. Since consumers regard the vehicles as perfect substitutes in the model, no consumer would pay more or less for an Impala with flexible-fuel capacity, and the automaker sets a single price for all Impalas. In reality, some consumers surely prefer flexible-fuel vehicles, while other consumers may even have a distaste for such vehicles. This will not matter for our result so long as the marginal consumer is indifferent, as we argue below. Later, we present empirical evidence that marginal consumers indeed do not value flexible-fuel capacity, proving our assumption here innocuous.

## 2.2 Fuel-economy standards

Fuel-economy standards impose a constraint that sets a minimum average mileage for the automaker’s fleet, taking into account the flexible-fuel vehicle loophole. The law also imposes a second, “backstop” constraint, which effectively limits the automaker’s ability to boost its fuel-economy rating using flexible-fuel vehicles. The first constraint takes the following form:

$$1 / \left( \sum_{j \in \mathcal{M}} \frac{q_j(p, m)}{Q} \cdot \frac{\theta_j \beta + (1 - \theta_j)}{m_j} \right) - \sigma \geq 0, \quad (2)$$

where  $\sigma$  is the fuel-economy standard in miles per gallon,  $m_j$  is the mileage of model  $j$ ,  $\beta \in [0, 1]$  is the incentive for flexible-fuel vehicles,  $Q = \sum_{j \in \mathcal{M}} q_j(p, m)$  is the automaker’s total sales volume, and all other parameters are as above. The constraint requires that an automaker’s AMFA fuel economy—that is, the sales-weighted harmonic-average mileage of the automaker’s vehicles, calculated using flexible-fuel incentives—exceed the CAFE standard of  $\sigma$ .

Current legislation fixes the flexible-fuel incentive at  $\beta \approx 0.6$ , giving automakers with binding constraints a strong implicit subsidy to produce flexible-fuel vehicles.<sup>5</sup> For a sense of how strong this incentive is, note that adding flexible-fuel capacity increases a vehicle’s effective mileage by about  $1/0.6 - 1 \approx 67\%$ , which amounts to treating a flexible-fuel Hummer like a Toyota Camry or a flexible-fuel Camry like a Toyota Prius. Increasing a model’s flexible-fuel share increases average mileage because the standard treats flexible-fuel vehicles as though they achieve better mileage than they actually do.

It is convenient to rewrite this first constraint as follows:

$$1 / \left( \sum_{j \in \mathcal{M}} \frac{q_j(p, m)}{Q} \frac{1}{m_j} - (1 - \beta) \sum_{j \in \mathcal{M}} \frac{q_j(p, m)}{Q} \frac{1}{m_j} \theta_j \right) - \sigma \geq 0, \quad (3)$$

which clarifies that flexible-fuel vehicles relax the constraint by reducing sales-weighted average fuel consumption per mile.

The automaker is limited in its ability to improve fuel economy using the flexible-fuel loophole. This limit acts like a “backstop” on actual fuel economy by adding a second

---

<sup>5</sup>In practice  $\beta = \rho r g + (1 - \rho)$ , where  $\rho \in [0, 1]$  is the assumed fraction of miles that the vehicle drives using E85 ethanol,  $r > 1$  is the ratio of ethanol to gasoline fuel consumption per mile, and  $g \in [0, 1]$  is the assumed gasoline content of E85. The credit’s logic is that it purports to count only gasoline consumption when determining a vehicle’s contribution toward average fuel economy. Current legislation fixes  $\rho = 0.50$ , which dramatically overstates the fraction of miles that flexible-fuel vehicles actually run on ethanol, and sets  $g = 0.15$ , which is the fraction gasoline content of E85. In practice  $r$  varies slightly among flexible-fuel vehicles, averaging about 1.35, which implies that flexible-fuel vehicles achieve about 35% higher fuel economy on gasoline or  $1 - 1/1.35 = 25\%$  lower fuel economy on ethanol. We assume for simplicity that  $r$  is the same for all vehicles so that  $\beta$  is also the same for all vehicles.

constraint:

$$1/ \left( \sum_{j \in \mathcal{M}} \frac{q_j(p, m)}{Q} \cdot \frac{1}{m_j} \right) - (\sigma - \phi) \geq 0, \quad (4)$$

where  $\phi > 0$  is the limit on using the flexible-fuel incentive, and all other parameters are as above. This constraint requires that actual sales-weighted harmonic-average mileage exceed the less-stringent standard of  $\sigma - \phi < \sigma$ . Equivalently, the constraint requires that the automaker's actual fuel economy not fall short of the nominal fuel-economy standard by more than  $\phi$  miles per gallon. Legislation fixes this limit at  $\phi = 1.2$  miles per gallon.

### 2.3 Choosing optimal flexible-fuel shares

It is helpful to think of the automaker as solving a two-stage maximization problem. First, the automaker pays the fixed costs to engineer flexible-fuel capacity on whichever models it chooses. Then the automaker sets flexible-fuel shares for these models. Variable profits in the second stage depend on the combination of models engineered to be flexible-fuel capable in the first stage. Thus, the automaker chooses flexible-fuel models optimally in the first stage to maximize second-stage variable profits minus first-stage fixed costs. We remain agnostic as to the competitive behavior automakers use to arrive at an equilibrium in vehicle prices, quantities, and mileage. We simply assume that some equilibrium mapping from prices and mileage to sales quantities exists, and that automakers choose flexible-fuel shares optimally given this mapping.

The Lagrangian for the automaker's second-stage maximization problem is given by:

$$\begin{aligned} \mathcal{L} = \sum_{j \in \mathcal{M}} (p_j - c_j - \alpha_j \theta_j) q_j + \lambda \left[ 1/ \left( \sum_{j \in \mathcal{M}} \frac{q_j}{Q} \frac{1}{m_j} - (1 - \beta) \sum_{j \in \mathcal{M}} \frac{q_j}{Q} \frac{1}{m_j} \theta_j \right) - \sigma \right] \\ + \mu \left[ 1/ \left( \sum_{j \in \mathcal{M}} \frac{q_j}{Q} \cdot \frac{1}{m_j} \right) - (\sigma - \phi) \right], \end{aligned} \quad (5)$$

where  $\lambda$  and  $\mu$  are the shadow prices on the constraints, all other variables are as above, and we have suppressed the arguments of functions for convenience. Flexible-fuel shares

are choice variables only for models on which the automaker has paid the fixed engineering costs; flexible-fuel shares are zero for other models. When the constraints are binding, the shadow prices implicitly tax inefficient models and subsidize efficient models. The shadow prices also quantify the marginal cost, in terms of lower profits, resulting from tighter fuel-economy standards. Equivalently, the shadow prices quantify the marginal benefit of looser standards. We estimate the first of these shadow prices by examining the loophole for flexible-fuel vehicles. This shadow price is revealed by the first-order conditions for flexible-fuel shares immediately below. We show empirically that the second shadow price is usually zero.

## 2.4 First-order conditions for flexible-fuel shares reveal marginal compliance costs

Differentiating the Lagrangian with respect to the flexible-fuel share of model  $k$  leads to the following first-order condition:

$$-\alpha_k + \lambda \frac{1 - \beta}{m_k Q} M^2 = 0. \quad (6)$$

where  $q_k$  factors out of both terms, and  $M$  is the automaker's sales-weighted harmonic-average mileage calculated using flexible-fuel incentives, which is given by the first term in equation (2). This first-order condition holds with equality for models whose flexible-fuel shares are strictly greater than zero and strictly less than one. At corner solutions the equality becomes an inequality. The first term is the incremental cost of flexible-fuel capacity. In the second term,  $\beta$  is the share of a flexible-fuel vehicle's fuel consumption per mile that contributes toward the automaker's fleet average, so  $(1 - \beta)/(m_k Q)$  is the reduction in average fuel consumption per mile that the automaker achieves when it adds flexible-fuel capacity to another unit. The presence of  $M^2$  converts this value to a marginal improvement in mileage, and the shadow price on the first constraint  $\lambda$  converts this improvement into

dollars of marginal benefits. Thus, the automaker simply equates the incremental cost of flexible-fuel capacity with the marginal benefit of a flexible-fuel vehicle in terms of relaxing the first constraint.

The first-order conditions for flexible-fuel shares reveal the shadow price on the first constraint, which is the key insight of this paper. Rearranging equation (6) gives:

$$\lambda = \frac{\alpha_k}{1/m_k} \frac{Q}{(1 - \beta)M^2}, \quad (7)$$

which holds with equality for models at an interior flexible-fuel share. The shadow price  $\lambda$  on the first constraint equals the incremental cost of adding flexible-fuel capacity divided by the corresponding improvement in AMFA fuel economy that flexible-fuel capacity affords. The automaker equates the marginal benefit of relaxing the constraint with the marginal cost of relaxing the constraint using the flexible-fuel loophole. This equation holds regardless of whether the second constraint is binding or not. Again, at corner solutions this equality becomes an inequality.

This shadow price is also related to the cost of CAFE standards. Differentiating the automaker's Lagrangian in equation (5) at the optimum with respect to the nominal fuel-economy standard gives marginal compliance costs in terms of lost profit:

$$\frac{\partial \mathcal{L}^*}{\partial \sigma} = -\lambda - \mu. \quad (8)$$

If the automaker does not exhaust the flexible-fuel loophole, the shadow price on the backstop constraint  $\mu$  is zero, and we can ignore the second term. Marginal compliance costs then equal the shadow price on the first constraint only.<sup>6</sup>

---

<sup>6</sup>Note that we calculate the marginal cost of tightening the CAFE standard  $\sigma$  while holding the limit on using the flexible-fuel loophole  $\phi$  constant. Other policy changes are possible and in general have different costs. For example, the marginal cost of reducing the limit  $\phi$  is simply  $\mu$ , which we are not able to estimate using our methodology. The marginal cost of tightening the CAFE standard  $\sigma$  while holding backstop fuel economy  $\sigma - \phi$  constant is  $\lambda$ , regardless of whether the backstop is binding or not. Neither of these policy changes is relevant here, as we assume that the backstop constraint is slack, implying that its shadow price is zero.

Substituting for the shadow price using equation (7) and then dividing by total production yields marginal compliance costs per vehicle as a function of known parameters:

$$\frac{\partial \mathcal{L}^*}{\partial \sigma} \frac{1}{Q} = -\frac{\alpha_k \cdot m_k}{(1 - \beta)\sigma^2}, \quad (9)$$

where we have replaced average mileage  $M$  with the fuel-economy standard  $\sigma$  because the first constraint is binding. Marginal compliance costs are then a simple function of mileage and the incremental cost of adding flexible-fuel capacity for any model with an interior flexible-fuel share. The automaker equates the marginal cost of relaxing the constraint using the flexible-fuel loophole with the marginal cost of relaxing the constraint through other means, such as by directly improving mileage or by selling a larger share of small vehicles. Constrained automakers that exploit the flexible-fuel loophole therefore reveal their marginal compliance costs, as long as they do not exhaust the loophole by running up against the backstop constraint.

## 2.5 Which models should get flexible-fuel capacity?

We do not attempt to model the automaker’s choice of flexible-fuel models completely, because we do not have the cost data needed to test the implications of such a model. We can, however, draw several heuristic points from the model and take these to the data. First, the combination of a fixed cost and constant incremental cost implies that automakers, at the optimum, will select one flexible-fuel model. They will only fit additional models with flexible-fuel capacity if the first model yields an insufficient gain in mileage when its flexible-fuel share is 100%.<sup>7</sup>

Second, the AMFA formula’s flexible-fuel credit mechanically treats inefficient vehicles more generously than efficient ones, as is clear from equation (3). All else equal, increasing a model’s flexible-fuel share has a bigger impact on relaxing the first constraint if the model’s

---

<sup>7</sup>As we note above, the appropriate level of analysis for the fixed cost is not a model but rather an engine type, which is what we analyze in the next section.

mileage is poor. This suggests that firms will likely fit inefficient models with flexible-fuel capacity. All else equal, we can also expect firms to choose models with higher sales volumes, as such models offer better opportunities to relax the constraint. That is, increasing a model's flexible-fuel share has a bigger impact on the first constraint when the model has a larger sales volume. In addition, choosing a model with high sales volumes might yield lower prices for parts by inducing competition among suppliers. This suggests that firms may prefer to fit popular models with flexible-fuel capacity.

We do not know the fixed or incremental cost of flexible-fuel capacity for individual models. Thus, in the empirical section we only ask if the selection of models is broadly consistent with automakers choosing a minimum number of models (to limit fixed costs) and choosing inefficient models with high sales volumes (to increase the impact on the constraint).

## 2.6 Additional considerations

Having established our key theoretical results, we now backtrack briefly to tie up several loose ends. Number one: While our mathematical model assumes that consumers ignore flexible-fuel capacity, the key result in equation (7) will hold as long as marginal consumers ignore it. That is, suppose that prices for flexible-fuel vehicles and their gasoline counterparts are the same in equilibrium, and that sales quantities do not change when an automaker marginally increases flexible-fuel shares. Then a constrained automaker will still equate the incremental cost of a flexible-fuel vehicle with its marginal benefit in terms of relaxing the first constraint, even if some consumers prefer flexible-fuel vehicles or have a distaste for flexible-fuel capacity. We show later that marginal consumers do not in fact value flexible-fuel capacity.

Number two: While our methodology yields the marginal cost of improving AMFA fuel economy, it does not necessarily give the marginal cost of improving actual fuel economy, which may be a parameter of interest. Our estimates closely approximate the marginal cost of improving actual fuel economy, however, when the automaker produces a small number of flexible-fuel vehicles. This is clear from the constraint in equation (3), where the difference

between AMFA fuel economy and actual fuel economy shrinks to zero with sales quantities for flexible-fuel vehicles. Formally, suppose the automaker produces only one type of vehicle. Then the first constraint weighted by its shadow price simplifies to

$$\lambda \left[ \frac{m}{\theta\beta + (1 - \theta)} - \sigma \right], \quad (10)$$

where  $m$  is the automaker's actual mileage,  $\theta$  is its flexible-fuel share, and the first term inside the brackets is the automaker's AMFA mileage. Differentiating with respect to actual mileage gives:

$$\frac{\lambda}{\theta\beta + (1 - \theta)}, \quad (11)$$

or the marginal benefit of relaxing the constraint by improving actual mileage, which the automaker will set equal to marginal costs. Suppose that  $\theta$  is small, say 0.15, which is the maximum flexible-fuel share for a binding light-truck standard of  $\sigma = 20.7$  miles per gallon and maximum flexible-fuel gain of  $\phi = 1.2$  miles per gallon. Then the marginal cost of improving actual fuel economy exceeds the marginal cost of improving AMFA fuel economy by a factor of just  $1/[0.15 \cdot 0.6 + (1 - 0.15)] \approx 1.06$ . The maximum flexible-fuel share for cars is even lower than 0.15, and in practice flexible-fuel shares average less than 0.06 during our study period.

Number three: There are two cases in which we are able to bound marginal compliance costs, even though we are unable to infer costs precisely. First, if the backstop constraint is binding, then the cost of improving fuel economy using the flexible-fuel loophole gives a lower bound on marginal compliance costs, because the shadow price on the backstop constraint is positive. Because the automaker complies with the fuel-economy standard and does not pay fines, we also know that costs are bounded above by the level of the fine.<sup>8</sup> Second, if a constrained automaker does not produce flexible-fuel vehicles, and if fixed engineering costs

---

<sup>8</sup>Technically, failing to comply is a civil infraction. Some analysts have suggested that the cost of non-compliance exceeds the \$55 fine. Automakers, they argue, fear that violating CAFE standards would damage their reputations and subject them to litigation by stockholders (Kleit 2004; Austin and Dinan 2005). Jacobson (2008) models these concerns as a fixed cost of non-compliance.

are zero, then the cost of improving fuel economy using flexible-fuel vehicles gives an upper bound on marginal costs. The shadow price on the backstop is zero, but the first-order conditions do not hold with equality. This upper bound does not hold for a general model with fixed engineering costs.

Finally, number four: Actual fuel-economy standards are more complicated than we describe above. First, automakers receive extra credit for vehicles that burn natural gas, electricity, and other alternative fuels. These vehicles all contribute toward the backstop limit of 1.2 miles per gallon. We could model these vehicles explicitly, but it would not change our key result that the incremental cost of installing flexible-fuel capacity reveals marginal compliance costs for automakers satisfying the conditions we set forth. In practice, automakers produce few alternative-fuel vehicles besides flexible-fuel vehicles.

Second, fuel-economy standards regulate light-duty trucks and passenger cars separately. Both fleets qualify for the same flexible-fuel incentive, and the limit of 1.2 miles per gallon applies to both fleets separately. Mathematically, this would imply a constraint on AMFA fuel economy and corresponding shadow price for each fleet, as well as a backstop constraint and corresponding shadow price for each fleet. Weights would then be given by a model's sales share within its respective fleet. Each of the above results would apply separately to the passenger-car and light-truck fleets. In what follows we distinguish between light-truck and passenger-car fleets.<sup>9</sup>

Third and finally, fuel-economy regulations allow “banking” and “borrowing.” An automaker that exceeds the standard in one year earns credits that it can use to comply in an earlier or future year to avoid paying fines. Banked credits expire after three years. If the automaker does not have banked credits, it can borrow credits in the short term and earn the credits back in a subsequent year. It must earn the credits back within three years to

---

<sup>9</sup>Fuel-economy standards also regulate domestic and import passenger cars separately. This distinction is not thought to be particularly important for present-day automakers (see Jacobson 2008). The one possible exception is Chrysler, which from 1999–2007 produced import cars through its European subsidiary Mercedes-Benz and paid CAFE fines on this fleet in 2004–2006. Chrysler separated from Mercedes starting in 2008.

avoid paying fines.<sup>10</sup> Fines are \$55 for every mile per gallon below the standard and scale with total production. Credits earned for light trucks can not be applied to passenger cars, and vice-versa.

### **3 Automakers exploit the flexible-fuel loophole**

The previous section showed that we are able to identify the marginal cost of CAFE regulation as long as four sufficient conditions hold. First, constrained automakers must exploit the flexible-fuel loophole to comply with CAFE standards. Second, automakers must offer a model with an interior flexible-fuel share. Third, automakers must not exhaust the flexible-fuel loophole by hitting the backstop constraint. Fourth, and finally, marginal consumers must not value flexible-fuel capacity. We demonstrate that the first, second, and third of these conditions hold using administrative data from the Department of Transportation’s National Highway Safety and Transportation Administration (NHTSA). These data record model names, production quantities, AMFA fuel economy, actual fuel economy, fuel type, and other vehicle attributes by model year. NHTSA collects these data to determine whether firms comply with CAFE standards. We demonstrate that the fourth condition holds using vehicle transaction data below.

#### **3.1 Constrained automakers exploit the flexible-fuel loophole to comply with CAFE standards but do not exhaust the loophole**

Table 1 summarizes fuel-economy performance and flexible-fuel production across automakers from 1993, the year the flexible-fuel loophole came into effect, and 2006. For both passenger-car and light-truck fleets, the table shows an automaker’s actual fleet-average fuel economy ignoring the flexible-fuel incentive, the difference between actual fuel economy and

---

<sup>10</sup>Moreover, a model’s “year” is itself a choice parameter that automakers can manipulate to comply with fuel-economy regulations. For example, suppose that Ford’s lineup of trucks for the 2008 model year was relatively efficient. Ford could stop selling the 2007 version of its gas-guzzling Excursion early in the 2007 calendar year, and begin selling the 2008 version to include with its relatively efficient 2008 models.

**Table 1:** Fuel-economy performance and flexible-fuel production 1993–2006

Firm	Passenger cars				Light trucks				All vehicles		
	Actual MPG	Over std.	% FFV	Paid fine?	Actual MPG	Over std.	% FFV	Paid fine?	Sales (mil.)	% mkt.	% truck
<u>Domestic</u>											
GM	27.9	0.4	0.0	no	20.5	-0.3	5.2	no	61.0	29.0	44.8
Ford	27.2	-0.3	2.5	no	20.3	-0.4	5.8	no	47.6	22.6	53.0
Chrysler	27.3	-0.2	0.9	yes	20.5	-0.3	6.0	no	33.3	15.8	65.8
<u>European</u>											
VW	28.8	1.3	0.0	no	19.9	-0.9	0.0	yes	3.9	1.8	3.4
BMW	25.8	-1.7	0.0	yes	20.6	-0.3	0.0	yes	2.6	1.2	13.4
Volvo	25.7	-1.8	0.0	yes					0.5	0.2	0.0
Porsche	23.8	-3.7	0.0	yes	18.5	-2.4	0.0	yes	0.3	0.1	18.3
<u>Asian</u>											
Toyota	31.0	3.5	0.0	no	22.6	1.8	0.0	no	21.8	10.3	38.2
Honda	32.0	4.5	0.0	no	25.0	4.1	0.0	no	14.9	7.1	23.2
Nissan	29.1	1.6	0.0	no	21.5	0.7	1.8	no	11.0	5.2	39.0
Total	28.6	1.1	0.6		20.8	0.1	4.5		210.7	100.0	45.1

Note: The table summarizes fuel-economy performance and flexible-fuel production during the 1993–2006 model years. Actual MPG is sales-weighted harmonic-average mileage ignoring flexible-fuel incentives. Fuel economy in excess of the standard is based on sales-weighted standards during the study period because the light-truck standard is increasing over time. The table omits several small European automakers with market shares less than 0.1% (e.g., Ferrari) and eight Asian automakers with market shares ranging from 0.1%–1.6%. (e.g., Hyundai and Subaru). The table does not distinguish between domestic and import passenger-car fleets; all fines for passenger cars were for imports. Chrysler includes Mercedes-Benz for 1999–2006. See text for details.

the fuel-economy standard, the fraction of the automaker’s vehicles that are flexible-fuel vehicles, and whether the automaker ever paid a fine between 1993 and 2006. The table also shows each automaker’s total production and market share during this time period, as well as the fraction of each automaker’s production that is light trucks.

Table 1 shows that all three domestic automakers produced vehicles whose actual fuel economy was below the standard during 1993–2006, and all three domestic automakers produced flexible-fuel vehicles. The only domestic fleet above the standard was the General Motors passenger-car fleet, and General Motors did not produce any flexible-fuel cars. In general, the domestic automakers would have paid fines based on their actual fuel economy

but did not, thanks to the incentive for flexible-fuel vehicles.<sup>11</sup> This evidence suggests that automakers only produce flexible-fuel vehicles to comply with fuel-economy standards, which is consistent with statements by automakers that flexible-fuel production would fall dramatically if the incentive were eliminated (U.S. Department of Transportation et al. 2002).

The only foreign firm to ever produce flexible-fuel vehicles is Nissan, which did not produce flexible-fuel vehicles until 2005–2006 when its actual light-truck fuel economy fell below the standard (details below). Honda and Toyota, who hold large shares of the American market, never produced flexible-fuel vehicles. If the value of adding flexible-fuel capacity exceeded its incremental cost in the present market equilibrium, we would expect Toyota and Honda to offer models with flexible-fuel capacity, assuming the gain in variable profits exceeded the fixed engineering costs. While European automakers consistently fall short of fuel-economy standards and regularly pay fines, they do not produce flexible-fuel vehicles. The European automakers have small sales volumes in the United States, however, which means that the fines they would avoid using flexible-fuel vehicles are less likely to compensate for fixed engineering costs.

Figures 1–4 provide more detail by plotting AMFA fuel economy (which accounts for the flexible-fuel incentive), actual fuel economy (which ignores the incentive), and fuel-economy standards over time for automakers that produce flexible-fuel vehicles.<sup>12</sup> The figures make clear that domestic automakers regularly depend on flexible-fuel vehicles to comply with fuel-economy standards. For example, Chrysler would have fallen short of the light-truck standard every year from 1999–2002 were it not for the flexible-fuel loophole, while Ford would have missed the light-truck standard every year from 1999–2005, save 2001. Because automakers can bank or borrow for up to three years, flexible-fuel vehicles that increase fuel economy in a year in which an automaker is already above the standard may still be valuable. For example, Chrysler’s flexible-fuel cars in 2003–2005 made up for deficiencies in

---

<sup>11</sup>Chrysler paid fines on its import passenger-car fleet only briefly during its marriage to Mercedes-Benz. Mercedes consistently paid fines prior to merging with Chrysler in 1999.

<sup>12</sup>Our calculations for AMFA fuel economy include a small number of natural gas vehicles and other alternative-fuel vehicles.

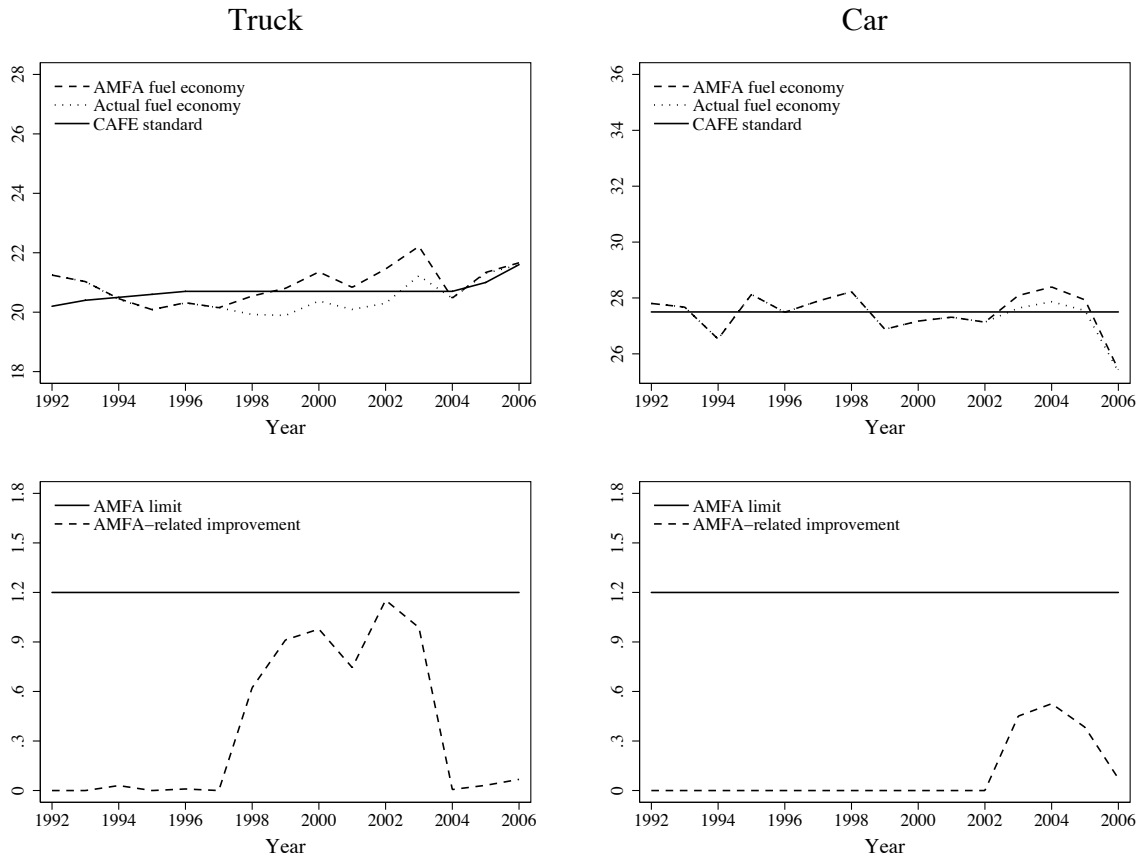
2000–2002 and 2006.

Figures 1–4 also plot the difference between AMFA fuel economy and actual fuel economy in each year, as well as the limit of  $\phi = 1.2$  miles per gallon. NHTSA ignores any gain in fuel economy above this threshold when calculating an automaker’s compliance in a given year, and an automaker is not able to bank or borrow anything above this limit. Automakers therefore have no incentive to produce above the limit unless marginal consumers value flexible-fuel capacity. As expected, automakers rarely exceed this limit. Chrysler came close with its light-truck fleet in 2002 but did not exceed the limit. Ford and General Motors briefly exceeded the limit for their light-truck fleets in 2003–2004, but reduced flexible-fuel shares in 2005. Note that the gain in mileage from using the flexible-fuel loophole is roughly proportional to the fraction of vehicles with flexible-fuel capacity, assuming the gain in mileage is relatively small. This implies, for example, that Chrysler, which gained about 0.5 miles per gallon using the flexible-fuel provision in 2004, could have roughly doubled its production of flexible-fuel vehicles in 2004 without exceeding the limit.

In general, the figures show that fuel-economy standards were binding for domestic automakers during 1993–2006 and that automakers would have paid fines were it not for flexible-fuel vehicles. The figures also show that automakers rarely exhaust the flexible-fuel loophole. These are two of the four conditions we need to infer marginal compliance costs by analyzing the cost of exploiting the flexible-fuel loophole.

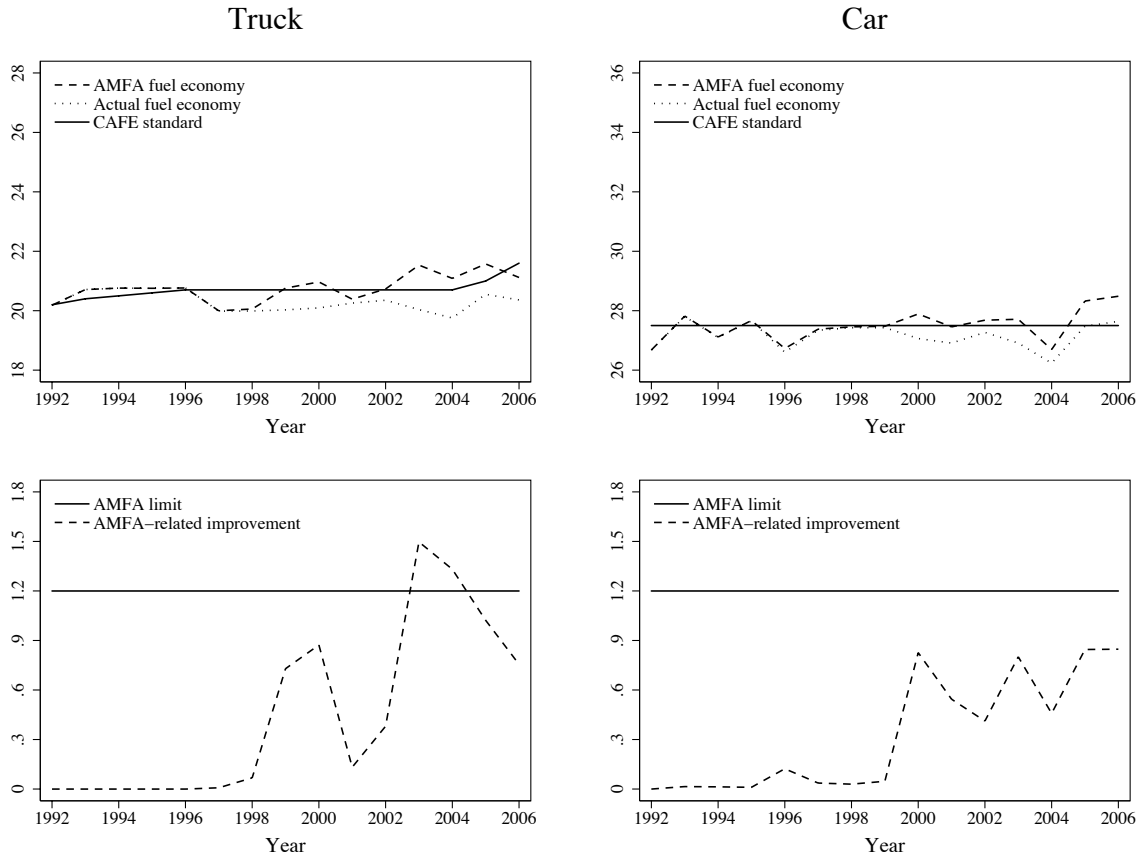
### **3.2 Automakers are at interior flexible-fuel shares and rarely install flexible-fuel capacity on more than one model**

Our model makes several broad predictions about flexible-fuel shares when automakers exploit the flexible-fuel loophole to comply with CAFE standards. First, fixed engineering costs imply that automakers will not install flexible-fuel capacity on multiple models when any single model is sufficient to take full advantage of the flexible-fuel incentive. Table 2 lists, for each automaker and fleet, the number of engine sizes that include a flexible-fuel



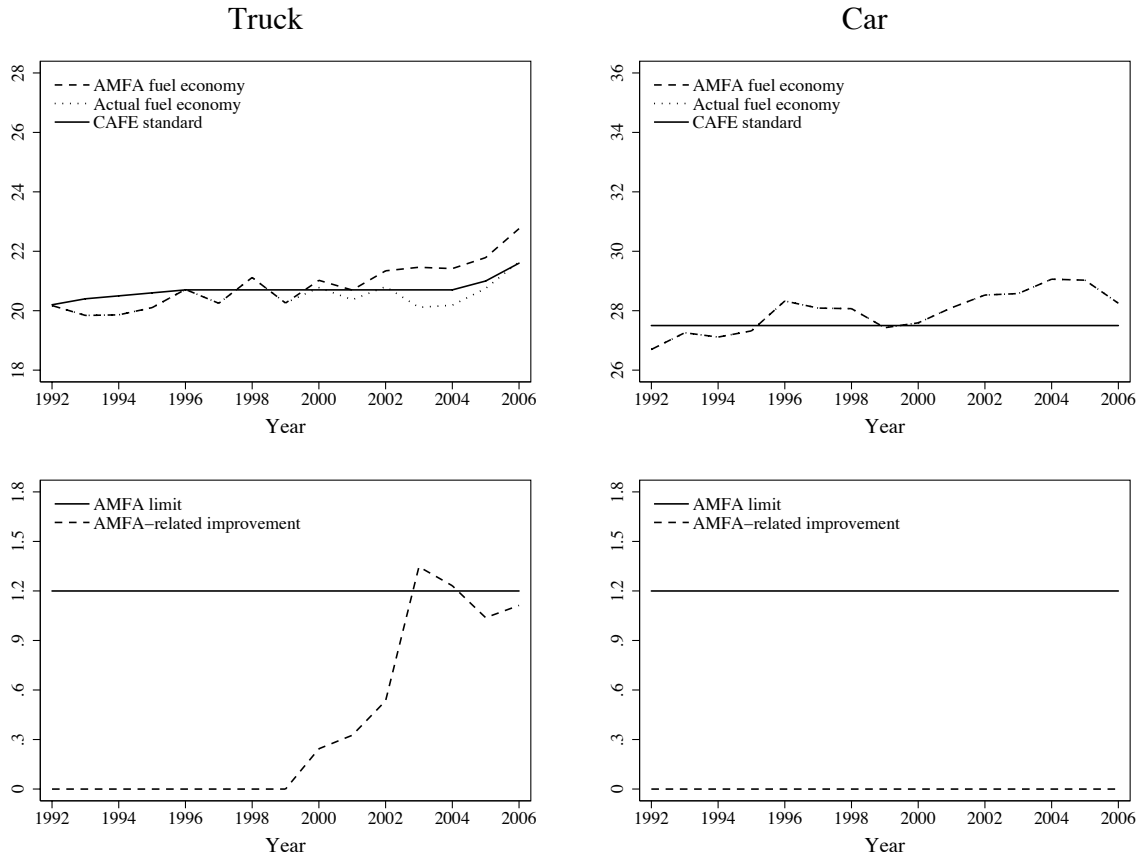
**Figure 1:** Chrysler fuel economy

Note: Top two figures show AMFA fuel economy and actual fuel economy for Chrysler’s light-truck and passenger-car fleets for model years 1992–2006. Figures also show fuel-economy standards. AMFA incentives began in 1993. Bottom two figures show annual increase in fuel economy attributable to AMFA incentives and the 1.2 mile-per-gallon limit. Regulations ignore any gain above this limit when calculating an automaker’s annual fuel economy. Chrysler merged with Mercedes-Benz in 1998 and began averaging fuel economy with Mercedes in the 1999 model year. Fuel economy for 1992–1998 does not include Mercedes.



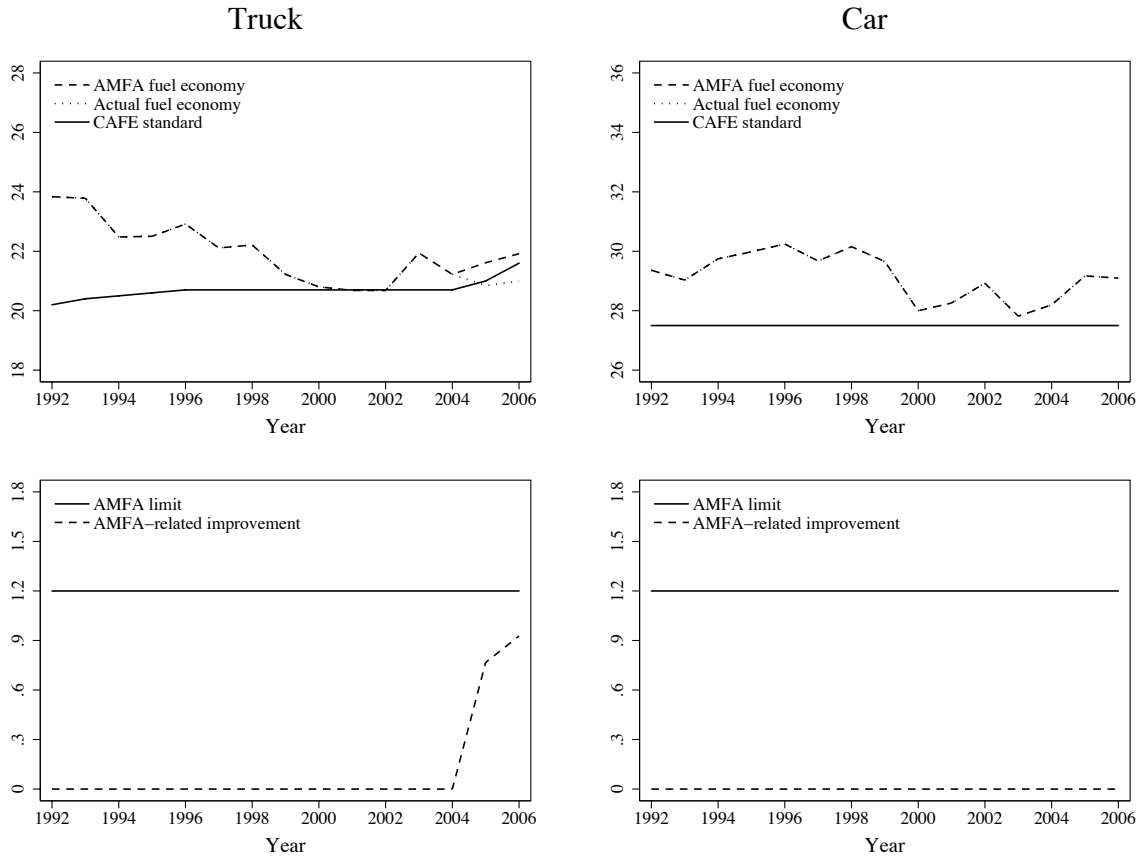
**Figure 2:** Ford fuel economy

Note: Top two figures show AMFA fuel economy and actual fuel economy for Ford's light-truck and passenger-car fleets for model years 1992–2006. Figures also show fuel-economy standards. AMFA incentives began in 1993. Bottom two figures show annual increase in fuel economy attributable to AMFA incentives and the 1.2 mile-per-gallon limit. Regulations ignore any gain above this limit when calculating an automaker's annual fuel economy.



**Figure 3:** General Motors fuel economy

Note: Top two figures show AMFA fuel economy and actual fuel economy for General Motors light-truck and passenger-car fleets for model years 1992–2006. Figures also show fuel-economy standards. AMFA incentives began in 1993. Bottom two figures show annual increase in fuel economy attributable to AMFA incentives and the 1.2 mile-per-gallon limit. Regulations ignore any gain above this limit when calculating an automaker’s annual fuel economy.



**Figure 4:** Nissan fuel economy

Note: Top two figures show AMFA fuel economy and actual fuel economy for Nissan’s light-truck and passenger-car fleets for model years 1992–2006. Figures also show fuel-economy standards. AMFA incentives began in 1993. Bottom two figures show annual increase in fuel economy attributable to AMFA incentives and the 1.2 mile-per-gallon limit. Regulations ignore any gain above this limit when calculating an automaker’s annual fuel economy.

**Table 2:** Number of engine sizes with flexible-fuel capacity

	Chrysler Domestic cars	Chrysler Import cars	Chrysler Trucks	Ford Domestic cars	Ford Trucks	General Motors Trucks
1996				1/8		
1997				1/6		
1998			1/9	1/6		
1999			1/12	1/6	1/9	
2000			1/13	1/7	1/10	1/10
2001			1/14	1/6	1/13	1/10
2002			1/15	1/6	2/11	1/12
2003	1/6	1/11	1/15	1/7	2/11	1/10
2004	1/6	2/12	1/11	1/6	1/11	1/12
2005	1/8	2/9	2/13	1/7	1/10	1/11
2006	1/6		2/14	2/7	1/9	1/13

Note: Table shows number of engine sizes that have flexible-fuel capacity for each fleet in each year, as well as the total number of engine sizes. Table omits fleets with no flexible-fuel vehicles.

version, as well as the total number of engine sizes that each automaker produces. Engine size serves as a proxy for engine type, which is the relevant “model” when thinking about fixed engineering costs. The table shows that in any given year automakers typically install flexible-fuel capacity on only one engine size per fleet, as our model predicts. They never install flexible-fuel capacity on more than two engine sizes.<sup>13</sup>

Our model also predicts that if incremental costs and fixed engineering costs are the same across models, automakers will tend to install flexible-fuel capacity on inefficient models, as this yields bigger gains in average mileage. Automakers will also tend to install flexible-fuel capacity on models with higher sales volumes, so as to realize the maximum gain in flexible-fuel incentives. Figure 5 plots flexible-fuel shares and sales-weighted average fuel consumption per mile by engine size for vehicles produced from 1993–2006. Flexible-fuel vehicles are not particularly inefficient relative to other vehicles. Automakers do avoid

<sup>13</sup>In some cases there is a one-to-one relationship between engine size and model name, in which case the distinction is irrelevant, but some models with different names share the same engines (e.g., the Ford Explorer and Explorer Sport Trac), and some models are effectively the same vehicle (e.g., the Ford Explorer and Mercury Mountaineer). Note that automakers do not necessarily incur fixed engineering costs in every year, as vehicle characteristics remain largely unchanged between major redesigns.

installing flexible-fuel capacity on models with low sales volumes, which in the figure are proportional to circle sizes.<sup>14</sup> The fact that mileage and sales volume do not precisely predict flexible-fuel status may simply reflect considerable heterogeneity in fixed engineering costs, which are unobservable.

Finally, figure 5 indicates that flexible-fuel shares were less than one for all engine sizes on which automakers installed flexible-fuel capacity from 1993–2006. This is the third of four conditions we need to infer the marginal cost of tighter CAFE standards. In summary, automakers respond as predicted to flexible-fuel incentives, and the first three conditions we need to infer marginal compliance costs hold. It only remains to show that marginal consumers do not value flexible-fuel capacity.

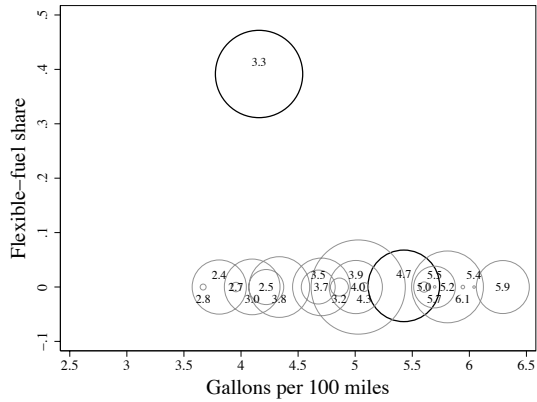
## 4 Marginal flexible-fuel consumers do not value flexible-fuel capacity

Next, we provide empirical evidence based on nearly one-million new vehicle transactions that marginal consumers do not value flexible-fuel capacity. This is important because our key result—that constrained automakers equate the marginal cost of improving fuel economy using flexible-fuel vehicles with the marginal cost of improving fuel economy through other means—depends on the marginal consumer having zero valuation. When combined with the evidence we present above that automakers use flexible-fuel vehicles to comply with CAFE standards, install flexible-fuel capacity on some but not all units for their flexible-fuel models, and do not exhaust the flexible-fuel loophole, the zero valuation implies that we can fully identify marginal compliance costs.

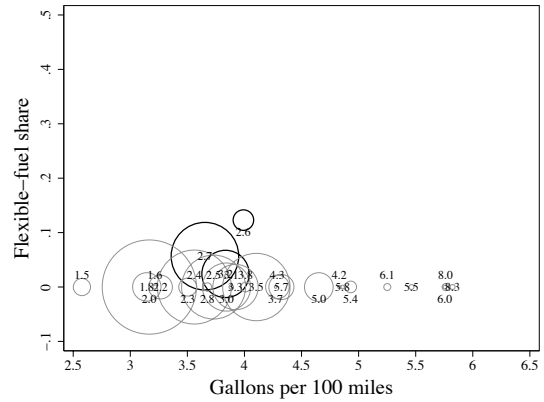
Rosen (1974) shows that what matters for equilibrium prices in a hedonic framework is the valuation of marginal agents. We suspect that some consumers would pay more for

---

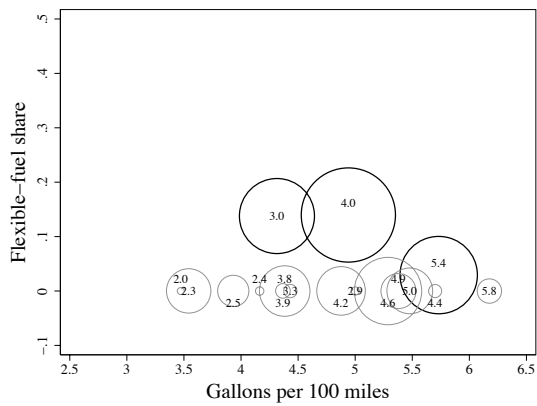
<sup>14</sup>Note that the figure does not control for the number of years that various models were offered, however, so sales volumes for some engine sizes may appear artificially low.



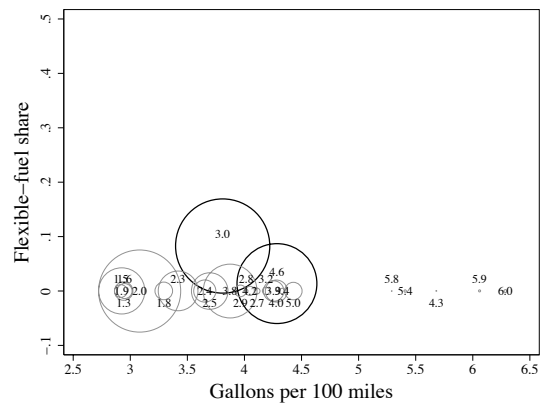
(a) Chrysler trucks



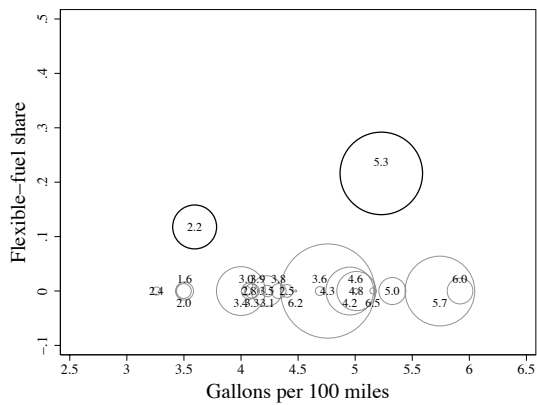
(b) Chrysler cars



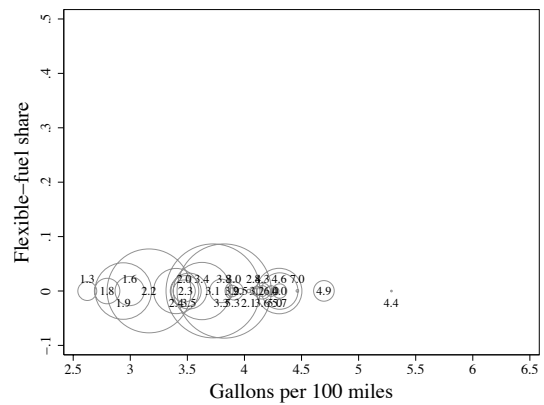
(c) Ford trucks



(d) Ford cars



(e) General Motors trucks



(f) General Motors cars

**Figure 5:** Flexible-fuel shares by engine size and fuel consumption

Note: Figure is based on NHTSA fuel-economy compliance data for 1993–2006 model years. Flexible-fuel share is the fraction of units for each engine size that has flexible-fuel capacity. Fuel consumption per 100 miles is the sales-weighted average for each engine size. Circle sizes are proportional to sales. Dark circles indicate that flexible-fuel shares exceed zero.

a vehicle with flexible-fuel capacity, but that the flexible-fuel loophole leads automakers to supply flexible-fuel vehicles in sufficiently large quantities that marginal consumers are indifferent.<sup>15</sup> We show that automakers sell many flexible-fuel vehicles to consumers who have no access to ethanol, and we estimate that the price premium for flexible-fuel vehicles is approximately zero. These results imply that marginal consumers indeed do not value flexible-fuel capacity.

These findings are consistent with evidence that many consumers are unaware that they own flexible-fuel vehicles, particularly in earlier years. For example, a report by several federal government agencies in 2002 concluded that “many people who have purchased flexible-fuel vehicles do not know they could use E85” (U.S. Department of Transportation et al. 2002), and a major ethanol-producing firm found that 70% of flexible-fuel vehicle owners surveyed in 2005 did not know they owned flexible-fuel vehicles (Wald 2005).

## 4.1 New vehicle transaction data

Our vehicle transaction data come from an industry source that collects data directly from a nationally representative sample of dealers. The data contain detailed information on new vehicle prices and characteristics for millions of transactions from 2000–2007. In addition to transaction prices, we observe manufacturer rebates, trade-in prices, and trade-in market values, which allow us to adjust prices for rebates and any difference between the price a dealer pays for a trade-in vehicle and the trade-in’s actual market value. We also observe interest rates and other information for dealer-financed transactions, allowing us to control for financing incentives.<sup>16</sup> Finally, we observe the calendar date of each transaction and the

---

<sup>15</sup>If automakers are able to price discriminate, they may be able to generate revenue from flexible-fuel capacity, even if marginal consumers are indifferent.

<sup>16</sup>We calculate the value of financing incentives in dealer-financed transactions by comparing a car buyer’s actual stream of monthly payments to the payment stream she would have faced at a market interest rate. We calculate the actual stream of monthly payments using the loan’s size, term, and dealer APR. We calculate an alternative stream of payments using the market-average APR for new car loans through commercial banks from the Federal Reserve Board. The Fed reports average interest rates every three months. We calculate interest rates for intervening months using linear interpolation. Finally, we calculate the present value of each payment stream using a 4% annual rate of pure time preference. The value of the financing

state in which the transaction took place, as well as the buyer’s age and gender. We deflate all prices by the consumer price index for all urban consumers and all items from the U.S. Bureau of Labor Statistics.

To isolate the value of flexible-fuel capacity, we identify flexible-fuel vehicles and comparison vehicles that are identical along every observable dimension, except fuel type. The transaction data include each vehicle’s truncated vehicle identification number (VIN), which provides information about a vehicle’s make, model, model year, body style, number of doors, drive type, transmission, engine displacement, number of cylinders, and aspiration (e.g., turbo-charged). The data also record each vehicle’s fuel type. We focus on flexible-fuel and gasoline vehicles, but the data also include diesels, gasoline-electric hybrids, and other fuel types. Restricting the sample to flexible-fuel vehicles and comparable gasoline-only vehicles gives an estimation sample of nearly 666,000 observations.<sup>17</sup>

Table 3 presents summary statistics for estimation final sample, while Table 4 lists model names and quantities for flexible-fuel models and comparison vehicles. At the end of the day, the detailed transaction data allow us to identify and compare, for example, the price of a gasoline-only 2006 Ford F150 extended-cab pickup with a 5.4L V8 engine and manual transmission to the price of a flexible-fuel 2006 Ford F150 extended-cab pickup with a 5.4L V8 engine and manual transmission. The data do not, however, include information about various options that may be installed. We investigate whether the value of such options is correlated with flexible-fuel capacity below.

In addition to these transaction data, we collect information on ethanol refueling locations from the Department of Energy’s Alternative Fuels Data Center, which we use to calculate

---

incentive is the difference between these two present values. These calculations are identical to Corrado et al. (2006).

<sup>17</sup>We first cross-reference fuel types in our data with information from the National Ethanol Vehicle Coalition, which lists model names, years, engine sizes, and VIN identifiers (usually the 8th digit) for flexible-fuel vehicles. We omit models that do not also appear in the Coalition’s list, as some vehicles in our sample are actually natural-gas dual-fuel vehicles. For the flexible-fuel vehicles that remain, we identify comparable gasoline vehicles based on observable characteristics, including VINs that exclude flexible-fuel identifiers. This gives nearly 900,000 preliminary observations. We omit about one-quarter of these observations, for which we observe a single VIN or more than two VINs per vehicle type, to minimize the chance of unobserved characteristics being correlated with flexible-fuel capacity.

**Table 3:** Summary statistics

Variable	Mean	Std. Dev.	Min.	Max.	Obs.
flexible-fuel vehicle	0.62	0.48	0	1	665887
transaction price	31,229.62	8,352.92	-10,994.38	75,002.08	665,887
suggested retail price	37,139.43	8,694.88	0	206,606.53	249,706
manufacturer rebate	2,415.44	2,021.8	0	11,409.17	665,887
inventory days	73.08	85.63	1	805	644,291
loan at dealer	0.75	0.43	0	1	576,274
interest rate (% APR)	5.51	4.22	0	29.99	427,656
down payment	7,347.18	7,399.25	-10,994.01	55,054.91	432,137
monthly payment	590.1	195.7	13.39	3,836.9	427,656
loan term (months)	62.44	11.14	12	96	427,656
trade-in vehicle	0.51	0.5	0	1	665,887
trade-in balance	1,347.07	2,730.48	-23,974.05	30,170.07	341,293
age of buyer	44.94	13.43	16	107	580,964
female buyer	0.27	0.45	0	1	596,987
ethanol availability (%)	0.17	0.68	0	8.10	665,887

Note: Table shows summary statistics for final estimation sample based on flexible-fuel vehicles and their gasoline-only counterparts. See text for details.

the total number of ethanol stations in each state in each month from 2000–2007.<sup>18</sup> We calculate percent ethanol availability by dividing by the total number of retail gasoline stations in each state using information from National Petroleum News.<sup>19</sup>

## 4.2 Many flexible-fuel vehicle buyers do not have access to ethanol

Our first step is to analyze the relationship between the availability of retail ethanol in a consumer’s state of residence and the geographic allocation of flexible-fuel vehicles. Our reasoning is that if a large number of vehicles are sold in states that lack ethanol, it is highly unlikely that marginal consumers value flexible-fuel capacity. Our analysis indicates that while there is a positive correlation between ethanol availability and flexible-fuel sales across

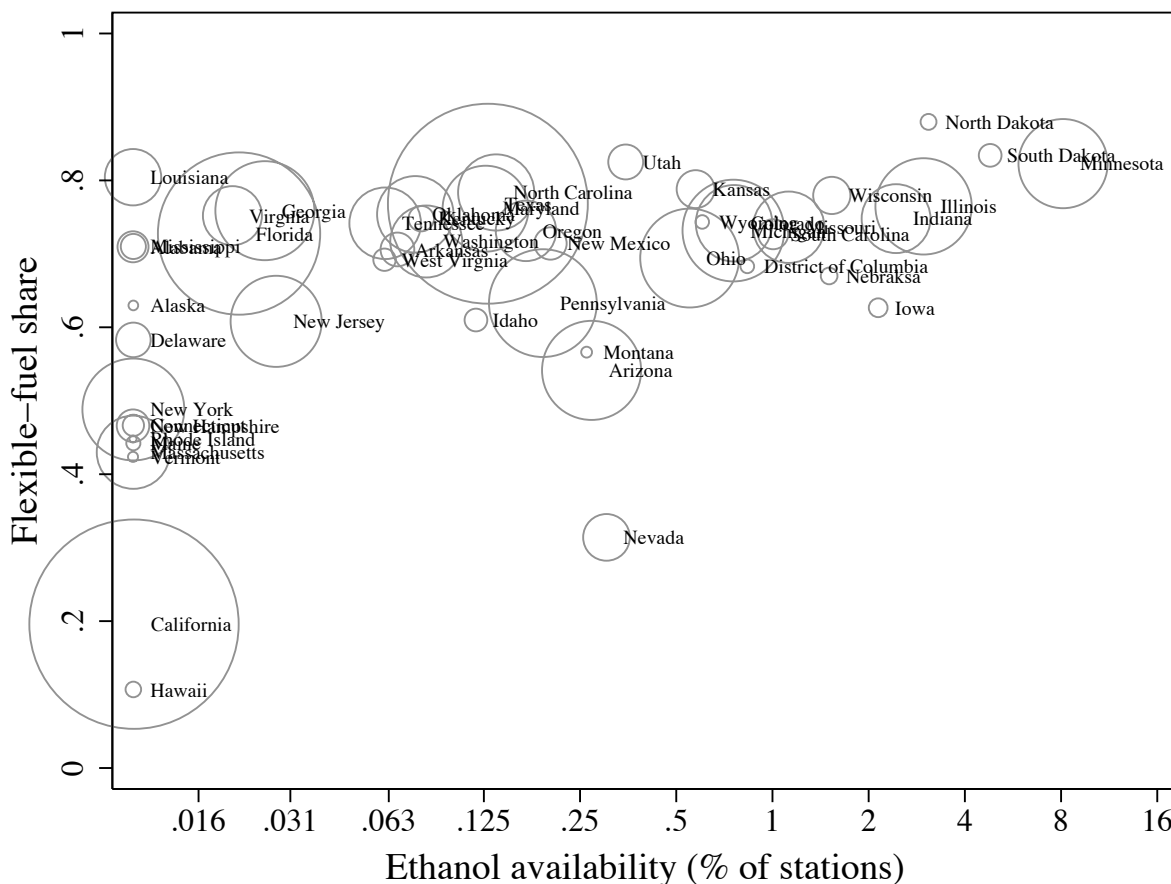
<sup>18</sup>The data do not systematically record open dates, but they do record the date when each station was added to the database. We assume that add dates approximate open dates. The Department of Energy began collecting these data in 1995, and new stations are added regularly, so our calculations based on add dates give a fairly accurate picture of how ethanol availability evolved during our sample period.

<sup>19</sup>Although National Petroleum News reports data annually, we divide by the mean number of retail gasoline stations in each state from 2000–2006, because the data collection process appears to vary from year to year.

**Table 4:** Flexible-fuel models in the data sample

<b>Model</b>	<b>Gasoline-only</b>	<b>Flexible-fuel</b>	<b>Total</b>
Armada	1,165	1,506	2,671
Aspen	119	565	684
Avalanche	1,473	16,208	17,681
B3000	1,350	773	2,123
Caravan	5,959	13,612	19,571
Cherokee	393	1,311	1,704
Commander	111	667	778
Crown Victoria	85	236	321
Dakota	39	46	85
Durango	2,677	212	2,889
Explorer	41,677	70,855	112,532
Express	65	58	123
F150	26,579	26,322	52,901
Grand Marquis	1,471	4,583	6,054
Impala	796	19,731	20,527
Monte Carlo	17	1,376	1,393
Mountaineer	6,026	4,647	10,673
Ranger	4,355	1,743	6,098
S10	3,245	6,986	10,231
Sable	1,237	37	1,274
Savana	62	12	74
Sebring	4,693	2,180	6,873
Sierra	7,028	4,120	11,148
Silverado	16,801	9,217	26,018
Sonoma	735	1,680	2,415
Stratus	1,872	11	1,883
Suburban	17,112	61,764	78,876
Tahoe	45,605	75,919	121,524
Taurus	8,626	8,574	17,200
Terraza	149	14	163
Titan	19,926	20,342	40,268
Town Car	1,009	2,585	3,594
Town & Country	2,416	10,126	12,542
Uplander	125	46	171
Voyager	1,510	6,565	8,075
Yukon	24,055	40,695	64,750
Total	250,563	415,324	665,887

Note: Table shows flexible-fuel models and quantities in estimation sample. Sample excludes flexible-fuel models with a single VIN or more than two VINs per vehicle type. See text for details.



**Figure 6:** Flexible-fuel shares and ethanol availability

Note: Flexible-fuel share is the fraction of vehicles in the estimation sample that have flexible-fuel capacity. Ethanol availability is the maximum fraction of stations that offer ethanol at any time during 2000–2007. Sizes of circles are proportional to the number of observations. Figure sets availability to 0.01% for 13 states with zero ethanol stations to be compatible with log scaling. These states appear along the left-hand side of the figure. California’s peak availability is small but not zero.

states, this relationship is weak.

Figure 6 plots flexible-fuel shares and peak ethanol availability by state. We calculate flexible-fuel shares based on our estimation sample of flexible-fuel vehicles and comparison gasoline-only vehicles. Flexible-fuel shares for these vehicles range from 0.6–0.8 in most states. Flexible-fuel shares are substantially lower in California, where many flexible-fuel vehicles fail the state’s strict emissions laws, and in Hawaii and Nevada. For the remaining

states there appears to be a slight positive correlation between flexible-fuel share and ethanol availability, but the correlation is weak. Doubling ethanol’s availability ten times over only correlates with a 30% increase in flexible-fuel shares, and flexible-fuel shares are high all over the country.

A full 17% of the flexible-fuel vehicles in our estimation sample sell in states where there are no ethanol pumps or just a single pump, while more than 86% sell in states where ethanol is available at less than 1% of stations. It is difficult to imagine that more than a handful of consumers in these states are willing to pay for flexible-fuel capacity. Thus, automakers deciding on how many flexible-fuel vehicles to produce must have expected that the price premium for marginal vehicles would be zero.

We also test the relationship between flexible-fuel quantities and ethanol pumps statistically. We calculate the flexible-fuel share for each vehicle type in each state in each year. We also calculate the peak fraction of fueling stations that have an ethanol pump in each state in each year.<sup>20</sup> We then regress flexible-fuel shares on availability, controlling for vehicle-specific fixed effects. We do not include year controls because vehicle types already differentiate by model year.

Table 5 presents the estimation results. The coefficient on ethanol availability in regression (1) implies that increasing ethanol’s market penetration by 1% correlates with an increase in flexible-fuel shares of 0.047. This relationship might be biased by unobserved determinants of flexible-fuel shares across states, such as California’s strict emissions laws. Regression (2), however, which includes state dummy variables, finds a nearly identical correlation. Flexible-fuel shares correlate with differential changes in ethanol availability across states over time, as well as with differences in availability across states in any given year.

While these coefficient estimates are consistent with automakers allocating vehicles based in part on preferences, flexible-fuel shares are high everywhere, even in states with virtually no ethanol pumps. If automakers are “overproducing” flexible-fuel vehicles to exploit the

---

<sup>20</sup>Using the mean fraction of fueling stations with an ethanol pump in each year does not alter the results appreciably.

**Table 5:** Where are flexible-fuel vehicles allocated?

Controls	(1) State dummies excluded	(2) State dummies included
<i>percent ethanol availability</i>	0.047 (0.014)	0.048 (0.011)
observations	26105	26105
groups	517	517
R-squared (within)	0.02	0.16

Note: Dependent variable is flexible-fuel share within each vehicle-state-year group. Both regressions include vehicle-specific fixed effects. Standard errors in parentheses are clustered by state.

flexible-fuel loophole, then marginal consumers in these and other states are unlikely to value flexible-fuel capacity. Our estimates for the flexible-fuel price premium below are consistent with this hypothesis.

### 4.3 Consumers do not pay extra for flexible-fuel capacity

Given that automakers sell a large fraction of flexible-fuel vehicles to consumers who lack access to ethanol, one would expect the equilibrium price of flexible-fuel capacity to be zero. In the presence of market power or price discrimination, however, consumers in states with ethanol availability, such as Minnesota, might pay a premium, even if marginal consumers in other states do not. We compare the prices of vehicles with and without flexible-fuel capacity and find that their prices are not statistically different.

Anecdotal evidence from government and media reports suggests that automakers sometimes increased the manufacturer’s suggested retail price (MSRP) for flexible-fuel vehicles, but then netted-out these price increases with targeted rebates (U.S. Department of Transportation et al. 2002). In other media reports, automakers claim that they do not pass the cost of flexible-fuel capacity on to consumers (Kohn 2000; Williams 2008). We checked the

MSRPs of several flexible-fuel vehicles in May 2008 and found that list prices were the same as comparable gasoline-only vehicles. We examine whether or not transaction prices vary with fuel type using our vehicle transaction data.

We estimate the price premium for flexible-fuel vehicles using the following econometric specification:

$$p_{ijst} = \gamma F F V_{ijst} + \delta_{jst} + \epsilon_{ijst}, \quad (12)$$

where:  $p_{ijst}$  is the sales price that we observe in transaction  $i$  for vehicle type  $j$  in state  $s$  and in month  $t$ ;  $F F V_{ijst}$  is a dummy variable that equals one if the vehicle in the transaction is a flexible-fuel vehicle and zero otherwise;  $\delta_{jst}$  is a vehicle-state-month fixed effect; and  $\epsilon_{ijst}$  is an error term. We estimate the model using least-squares estimation and vehicle-state-month fixed effects.

The coefficient of interest is  $\gamma$ . This coefficient is the average price premium for flexible-fuel vehicles relative to comparable gasoline-only vehicles sold in the same place at the same time, which measures the marginal willingness to pay for flexible-fuel capacity.<sup>21</sup> The vehicle-state-month fixed effects given by  $\delta_{jst}$  are equivalent to including vehicle, state, and month dummy variables, as well as all relevant two-way and three-way interactions of these variables. The error term  $\epsilon_{ijst}$  reflects unobserved vehicle characteristics such as carpet floor mats, tinted windows, or other options that do not come standard in observed trim levels. The identification assumption is that this error term is uncorrelated with flexible-fuel capacity, conditional on state, month, and vehicle type:  $E[\epsilon_{ijst} \cdot F F V_j | \delta_{jst}] = 0$ .

Table 6 presents the estimation results for the model in equation (12). The coefficient in regression (1) indicates that the marginal consumer demands a \$22 price discount to purchase a flexible-fuel vehicle during the sample period, although this coefficient is not statistically

---

<sup>21</sup>Estimating implicit prices for a vehicle's fuel type or mileage can be challenging, given the strong collinearity these characteristics usually share with other attributes (see Espey and Nair 2005). This is not a problem here. Because we observe thousands of transactions for flexible-fuel models and their identical gasoline-only counterparts, we are able to control for vehicle attributes non-parametrically using vehicle-specific fixed effects and still estimate flexible-fuel premiums precisely. Most previous studies use annual cross-sectional data for vehicle list prices and control for vehicle attributes parametrically.

**Table 6:** Flexible-fuel premium

Controls	(1) All obser- vations	(2) Cash sales only
<i>FFV</i>	-22.07 (28.29)	-38.13 (60.19)
observations	665887	143869
groups	99398	52264
R-squared (within)	0.00	0.00

Note: Dependent variable in both regressions is sales price net of manufacturer rebates, financing incentives, and trade-in overallowance. Regression (2) estimates the model using transactions where the purchaser paid cash at the dealer (i.e., did not borrow or lease from the dealer), so financing incentives do not apply. Both regressions control for vehicle-state-month fixed effects. Standard errors in parentheses are clustered by vehicle-state-month cells. See text for further details.

different from zero.<sup>22</sup> When we restrict the analysis to cash transactions in regression (2) the flexible-fuel premium falls slightly to  $-\$38$  but is statistically indistinguishable from the estimate in regression (1). These results suggest that neither dealer-financed sales nor our adjustment for financing incentives change the estimates appreciably.<sup>23</sup>

If consumers had specific preferences for flexible-fuel vehicles, we would expect these preferences to correlate with consumer characteristics, such as age or income. This would lead to sorting on flexible-fuel capacity. Similarly, if automakers installed flexible-fuel capacity on models with low-value or high-value options packages, these packages would correlate with consumer characteristics, which would also lead to sorting. Our data allow us to test these hypotheses. Using the same econometric specification as in equation (12) above, we estimate

<sup>22</sup>These results are consistent with earlier work by Liu (2007), who estimates flexible-fuel premiums using annual nationwide data for suggested retail prices from 1996–2001. She estimates a premium of \$0.37.

<sup>23</sup>A select one-third of observations also include manufacturer-suggested retail prices. Using the same specification, we find that MSRPs are \$154 higher for flexible-fuel vehicles. This would appear to be consistent with anecdotal evidence that some automakers increased MSRPs to reflect incremental costs but then rebated the difference. When we limit our analysis to the MSRP sample, however, transaction prices are still \$121 higher for flexible-fuel vehicles. We are therefore hesitant to read too deeply into this MSRP estimate, as it is likely the result of sample selection.

**Table 7:** Are flexible-fuel transactions different?

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Days on lot	Dealer loan?	Interest rate	Total down	Monthly amount	Loan term	Trade auto?	Trade balance	Age of buyer	Female buyer?
<i>FFV</i>	-29.43 (1.07)	-0.011 (0.003)	-0.03 (0.03)	46.81 (50.34)	0.03 (1.08)	-0.17 (0.08)	-0.0002 (0.0030)	-19.13 (21.07)	0.15 (0.08)	-0.001 (0.003)
obs.	644291	576274	427656	432137	427656	427656	665887	341293	580964	596987
grps.	97097	95135	79231	79731	79231	79231	99398	75134	90386	94463
R-sq.	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Note: Dependent variables are: (1) days that vehicle was in dealer’s inventory prior to sale (2) indicator variable that equals one if buyer took out loan from dealer and zero if buyer purchased vehicle with cash; (3) APR interest rate conditional on loan from dealer; (4) down payment conditional on loan from dealer; (5) monthly payment conditional on loan from dealer; (6) loan term in months conditional on loan from dealer (7) indicator that equals one if buyer sold dealer a trade-in vehicle at time of purchase and zero otherwise; (8) trade-in amount minus trade-in market value conditional on trade-in vehicle; (9) age of first buyer listed on purchase agreement; (10) indicator variable that equals one if first buyer listed is female and zero otherwise. All regressions include vehicle-state-month fixed effects. Standard errors in parentheses are clustered by vehicle-state-month cells. See text for details.

the correlation between flexible-fuel capacity and other transaction characteristics. Sallee (2007) uses a similar approach to test whether the typical Prius buyer who purchased her vehicle when tax incentives were available is different from the typical buyer who purchased his vehicle when incentives were not available.

Table 7 presents the results of these regressions. The first regression indicates that flexible-fuel vehicles sold 29 days earlier than comparable gasoline-only vehicles sold in the same state at the same time. This is a fairly sizable difference given that vehicles in our sample remain in a dealer’s inventory an average of 73 days. Flexible-fuel vehicles may spend fewer days in inventory if they go disproportionately to dealers with high turnovers or if some consumers specifically request flexible-fuel vehicles. As long as these consumers are not marginal they could increase turnover without affecting prices.

None of the other transaction characteristics differ meaningfully between flexible-fuel and gasoline-only vehicles. Flexible-fuel buyers are no more or less likely to finance their

vehicles through dealers. Interest rates are no different, nor are down payments, monthly payments, or loan durations. Flexible-fuel and gasoline-only buyers trade in used vehicles just as often, and trade-in balances do not differ systematically. Finally, flexible-fuel and gasoline-only buyers are the same age and gender on average. In summary, we detect no meaningful differences between car buyers that purchase flexible-fuel vehicles and those that buy identical gasoline-only vehicles. Flexible-fuel vehicles spend fewer days in inventory, however, which is consistent with some buyers having specific preferences for flexible-fuel capacity. These buyers do not affect prices.

Overall, our analysis of prices and quantities suggests that automakers do not charge more for flexible-fuel vehicles, and, more specifically, that the marginal consumer does not value flexible-fuel capacity. This justifies the formulation of our model, which implicitly assumes that consumers ignore flexible-fuel capacity. With this evidence, along with the evidence we presented above that automakers exploit the flexible-fuel loophole to comply with CAFE standards, install flexible-fuel capacity on some but not all units, and do not exhaust the flexible-fuel loophole, we have shown that the four sufficient conditions that enable us to identify marginal compliance costs all hold for domestic automakers in recent years.

## 5 Estimating marginal compliance costs

Using our methodology, we now calculate marginal compliance costs for automakers that produced flexible-fuel vehicles. Equation (9) from above, which we repeat here for convenience, shows that the cost per vehicle of marginally increasing the CAFE standard is a function of both flexible-fuel vehicle attributes and regulatory parameters:

$$\frac{\partial \mathcal{L}^*}{\partial \sigma} \frac{1}{Q} = -\frac{\alpha_k \cdot m_k}{\sigma^2(1 - \beta)}, \quad (13)$$

where  $\alpha_k$  is the incremental cost of adding flexible-fuel capacity,  $m_k$  is actual mileage,  $\sigma$  is the nominal fuel-economy standard, and  $\beta$  is the AMFA incentive for flexible-fuel vehicles.<sup>24</sup>

We calculate marginal compliance costs by plugging in parameter values as follows. For the incremental cost of adding flexible-fuel capacity, we use a range of \$100–\$200 per vehicle, which we think gives a conservatively high estimate of costs.<sup>25</sup> Other parameters also vary over time and across flexible-fuel models, but much less so in percent terms. We calculate relevant mileage as the sales-weighted harmonic-average mileage of an automaker’s flexible-fuel vehicles. We assume, as above, that the flexible-fuel incentive is  $\beta = 0.6$ . Finally, while the standard for passenger cars remains 27.5 miles per gallon during the entire study period, the light-truck standard increases gradually from 20.4–21.6 miles per gallon. We therefore calculate a single, sales-weighted harmonic-average standard for each automaker, weighting the standard in each year by the automaker’s light-truck sales in that year. We calculate costs separately for light-truck and passenger-car fleets.

Table 8 presents our estimates of marginal compliance costs for the major domestic automakers and Nissan, who all produce flexible-fuel vehicles. Tightening the light-truck standard by one mile per gallon would cost these automakers \$11–\$28 in lost profit per vehicle, while tightening the standard for passenger cars would cost \$8–\$18 per vehicle. The ranges for each automaker derive from the assumed range of \$100–\$200 for incremental production costs, which we think is conservatively high. Costs are not identical because the mileage of flexible-fuel vehicles varies from automaker to automaker, as does the average

---

<sup>24</sup>In theory, this equation should hold separately for any model at an interior flexible-fuel share. As we showed above, however, an automaker will typically only have one such model, both in theory and in practice.

<sup>25</sup>Reliable sources put incremental costs as high as \$150–\$300 per vehicle before automakers began producing flexible-fuel vehicles in large quantities (U.S. Environmental Protection Agency 1990) to as low as \$25–\$50 currently (Alson 2008), while NHTSA put the range at \$100–\$200 when it ruled to extend the flexible-fuel provision in 2004 (U.S. Department of Transportation 2004). Recent reports in the popular press quoting automakers themselves are consistent with these ranges, with costs ranging from “\$70 to \$100 per vehicle, depending on engine size” (Williams 2008), to “at most a few hundred dollars more per car” (Barrionuevo and Maynard 2006). Some sources report costs at “high sales volumes,” implying that some cost estimates include average fixed costs. Rubin and Leiby (2000) cite a consulting report from 1995 that estimated fixed costs of \$4.2 million per model annually and incremental production costs of \$240 per vehicle. Finally, in 2008, an engineer working on flexible-fuel vehicles for a domestic automaker told us that a range of \$50–\$200 is reasonable.

**Table 8:** Marginal compliance cost per vehicle  
of tightening fuel-economy standards

<b>Automaker</b>	<b>Vehicle fleet</b>	
	<b>Trucks</b>	<b>Cars</b>
Chrysler	\$14–\$28	\$9–\$18
Ford	\$12–\$24	\$8–\$17
General Motors	\$11–\$22	\$9–\$18
Nissan	\$11–\$21	
CAFE fine	\$55	\$55
Jacobson (2007)	\$11–\$23	\$4–\$36

Note: The table shows estimates of marginal compliance costs per vehicle based on equation (13). Ranges assume an incremental cost of \$100–\$200 for adding flexible-fuel capacity. Calculations use the sales-weighted mean fuel-economy standard for each automaker and the sales-weighted mileage for each automaker’s flexible-fuel vehicles during 1993–2006. Estimate for the General Motors passenger-car fleet assumes that GM applied flexible-fuel capacity to a car of average mileage when it began producing flexible-fuel vehicles in 2007. Ford and General Motors exhausted the flexible-fuel loophole for their light-truck fleets in 2003–2004, so marginal compliance costs in at least those years are higher than what we estimate here. Their costs are bounded from above by the \$55 statutory fine, ignoring any implicit fixed cost for non-compliance. Chrysler pays fines on its import passenger-car fleet; costs based on our methodology are for domestic fleet only. Firms that serially pay fines have marginal cost equal to CAFE fine of \$55. Table also includes Jacobson (2008) estimates for comparison.

light-truck standard. We do not calculate compliance costs on a year-by-year basis, because banking and borrowing provisions allow automakers to equate marginal compliance costs over time.

Again, because the automaker is optimizing on the margin, these costs equal the marginal cost of improving AMFA fuel economy using flexible-fuel vehicles, as well as the marginal cost of improving AMFA fuel economy through other means. Our estimates therefore reflect lower profit margins on smaller, more efficient vehicles, as well as the difference between production costs and willingness to pay for improvements in vehicle efficiency. Recall that while AMFA and actual fuel economy are not the same, they are quite close in practice.

Nissan first produced flexible-fuel trucks in 2005–2006, revealing marginal compliance costs for at least those years. General Motors first began producing flexible-fuel cars in the 2007 model year. Assuming that the passenger-car standard is binding for General Motors toward the end of the study period, and that General Motors applied flexible-fuel capacity to cars with average mileage, then our methodology implies that GM’s marginal cost of compliance is \$9–\$18 per vehicle. Marginal costs for these automakers were as low as zero in earlier years when their fuel economy exceeded the standard and they did not produce flexible-fuel vehicles. Marginal compliance costs are \$55 per vehicle for automakers that serially pay fines, including Volkswagen and Porsche, and zero for unconstrained automakers, such as Honda and Toyota, none of whom produce flexible-fuel vehicles.

For comparison, table 8 includes the results of Jacobson (2008), who estimates marginal compliance costs for domestic automakers during 1997–2001 using a wholly different methodology.<sup>26</sup> He finds that tightening the fuel-economy standard for light trucks by one mile per gallon would cost domestic automakers \$11–\$23 per vehicle, depending on the automaker, while tightening the standard for passenger cars would cost \$4–\$36. These estimates are very close to what we estimate based on incremental costs for flexible-fuel vehicles. We find this overlap reassuring. Note that these costs are substantially lower than the \$55 fine that automakers pay when they fail to comply, which previous researchers have used as a measure of compliance cost (Goldberg 1998; Rubin and Leiby 2000; Austin and Dinan 2005; Liu and Helfand 2008).

Our cost estimates do have several limitations. First, like other estimates in this literature, our estimates reflect the cost of marginal increases in CAFE standards. They do not reflect engineering investments, capital expenditures, and other fixed costs that may be required for aggressive increases in mileage. These costs could be substantial. Second, our

---

<sup>26</sup>He estimates a system of demand elasticities for new vehicles, assumes that oligopolistic automakers engage in Nash-Bertrand pricing behavior, and then solves each automaker’s system of first-order conditions to impute marginal costs. He then assumes that the share of a model’s markup that goes to dealers is constant across an automaker’s models. This is his key identification assumption. He is then able to regress observed dealer markups over invoice on imputed costs and fuel consumption for each model. The estimated parameter on fuel consumption yields the shadow value of the fuel-economy constraint.

estimates reflect compliance costs during our study period and do not necessarily hold for current or future years. Vehicle characteristics, consumer preferences, and technology all evolve over time. Moreover, the structure of CAFE regulation is currently in flux, as regulators move toward “size-based” standards, which mandate higher mileage for firms that produce smaller vehicles. These reforms will undoubtedly impact compliance costs. Finally, our estimates do not reflect changes in consumer surplus resulting from tighter fuel-economy standards.

## 6 Would tightening CAFE standards increase social welfare?

To put our cost estimates in context, we provide back of the envelope calculations for the marginal external benefits of tighter fuel-economy standards assuming that automakers are forced to comply by improving actual fuel economy. Tighter fuel-economy standards reduce U.S. gasoline consumption, which lowers world oil prices, mitigates adjustment costs associated with oil price shocks, and reduces carbon dioxide emissions. Tighter standards reduce the cost of traveling a mile, however, which leads to increased travel and offsetting externalities, including noise, congestion, and traffic accidents. Net benefits are therefore sensitive to the elasticity of miles with respect to mileage.

Conventional, middle-of-the-road estimates for the external damage of greenhouse emissions and other parameters would put costs at roughly \$0.18 per gallon and \$0.10 per mile (Harrington et al. 2007), and the elasticity response at 0.1 (Small and Dender 2007). Assuming that the average truck travels 190,000 miles in its lifetime, the external benefit of tightening the standard for light trucks is  $-\$20$  per vehicle. The external benefit for cars is  $-\$24$ , assuming a car travels 162,000 miles.<sup>27</sup> That is, external costs more than offset

---

<sup>27</sup>We obtain information on average lifetime miles weighted by survival rates from the U.S. Department of Transportation (2008). The total externality per vehicle is given by  $E = c(M/\sigma) + kM$ , where  $c$  is the marginal external cost of gasoline per gallon,  $k$  is the marginal external cost of travel per mile,  $\sigma$  is the

external benefits. We are unable to perform a formal benefit-cost test, as our cost estimates do not include changes in consumer surplus. Jacobson (2008) finds that consumers bear over 80% of the welfare loss of tighter standards, however, which suggests that fuel-economy standards are unlikely to pass a benefit-cost criterion based on conventional assumptions, even though the cost to producers is small. This implies that the flexible-fuel loophole may actually increase welfare, by allowing firms to relax an inefficient CAFE constraint. Removing the CAFE standard itself would be better than keeping the loophole, however, as using the loophole to relax the constraint is costly.

We also calculate the implicit carbon price that would, given our cost estimates, make increasing CAFE standards welfare neutral. If we assume based on Jacobson’s (2008) findings that total private losses are five times producer losses, then the total marginal cost is \$55–\$140 for light trucks and \$40–\$90 for passenger cars. This implies break-even carbon prices of \$28–\$52 (trucks) and \$45–\$74 (cars) per metric ton of carbon dioxide. While these prices are substantially higher than conventional damage estimates of roughly \$15 per ton (Tol 2005), the Stern Report (2006) concludes that the benefit of reducing carbon dioxide emissions may be as high as \$85 per ton. Stern’s conclusions hinge on assuming extremely low discount rates, but Weitzman (2007) has separately concluded that taking into account structural uncertainty about the possibility of catastrophic climate change may lead to similarly large benefit estimates, with standard discounting assumptions. In any case, most studies conclude that a higher gasoline tax could achieve the same reduction in fuel consumption as CAFE at much lower cost (e.g., National Academy of Sciences 2002, Congressional Budget Office 2003, Austin and Dinan 2005, West and Williams 2005, and Jacobson 2008).

---

fuel-economy standard, and  $M$  is miles traveled. Differentiating with respect to the fuel-economy standard and then manipulating terms gives the marginal change in the externality:

$$\frac{\partial E}{\partial \sigma} = -c \frac{M}{\sigma^2} (1 - \xi) + k \frac{M}{\sigma} \xi, \tag{14}$$

where  $\xi$  is the elasticity of miles with respect to mileage. A negative value implies that tightening the CAFE standard yields net external benefits. Discounting at an annual rate of say 3% would reduce the magnitude of net benefits by about 20% but would not change its sign.

## 7 Conclusion

We analyze the market for flexible-fuel vehicles that burn ethanol. While interesting in its own right, this market is especially important because it indirectly provides information about the cost of tightening the fuel-economy standards that apply to all automobiles. Efforts to reduce gasoline consumption in the United States have historically focused on mandating vehicle efficiency through Corporate Average Fuel Economy (CAFE) standards. The merits of these standards are not always clear, in part because it is difficult to measure the cost of regulation in the absence of market prices and because automakers have an incentive to overstate the costs of compliance. Domestic automakers claim that aggressive increases in CAFE standards would cost them tens-of-billions of dollars in profit, force them to close plants and cut tens-of-thousands of jobs, increase car prices by thousands of dollars, and “cripple” the domestic auto industry (Byrne 2003; Bloomberg News 2007; Shepardson 2007).

We estimate that the cost of marginally tightening CAFE standards, as revealed by profit-maximizing behavior in the auto industry, is relatively small. To do so, we demonstrate that automakers exploit an incentive or “loophole” in CAFE regulation that allows them to relax CAFE standards by producing flexible-fuel vehicles. We show theoretically that constrained automakers will equate the marginal cost of improving fuel economy using flexible-fuel vehicles with the marginal cost of improving fuel economy through other means. Thus, because we can observe the cost of producing a flexible-fuel vehicle, automakers that produce flexible-fuel vehicles indirectly reveal their marginal compliance costs. Based on this approach, we estimate that tightening CAFE standards by one mile per gallon would cost domestic automakers \$8–\$28 in profit per vehicle, which is in line with recent estimates by Jacobson (2008) but substantially lower than the \$55 fine used in earlier research.

The difficulty of estimating compliance costs is not unique to the automobile industry. Researchers do not readily observe costs in the absence of tradable permits, and regulated firms rarely have an incentive to report their costs truthfully. The methodology developed in this paper demonstrates that regulatory loopholes may provide a way to overcome these

obstacles. One potential application is zoning laws, which restrict the height and density of buildings. In many cities, these laws feature “incentive zoning” clauses, which allow developers to exceed zoning restrictions in exchange for setting aside open space or providing other public goods. Researchers could infer the benefit to developers of easing height and density restrictions by examining how much developers spend on public goods to relax these constraints. In the realm of environmental policy, regulation is likely to increase significantly as policymakers around the world grapple with the implications of climate change. We suspect that some of these regulations will also feature incentives and loopholes like the one we use here to uncover CAFE compliance costs.

## References

- Alson, J. (2008, May). Personal communication with Jeff Alson of the U.S. Environmental Protection Agency.
- Anderson, S. T. (2008, April). The demand for ethanol as a gasoline substitute. Unpublished.
- Austin, D. and T. Dinan (2005, November). Clearing the air: The costs and consequences of higher CAFE standards and increased gasoline taxes. *Journal of Environmental Economics and Management* 50(3), 562–582.
- Barrionuevo, A. and M. Maynard (2006, May 1). Dual-fuel vehicles open mileage loophole for carmakers. *New York Times*.
- Bloomberg News (2007, June 16). Fuel plan would ‘cripple’ chrysler, chief says. *Bloomberg News*.
- Byrne, R. (2003). Life in the slow lane: Tracking decades of automaker roadblocks to fuel economy. Union of Concerned Scientists Report.
- Congressional Budget Office (2003, December). The economic costs of fuel economy stan-

dards versus a gasoline tax.

- Corrado, C., W. Dunn, and M. Otoo (2006, January). Incentives and prices for motor vehicles: What has been happening in recent years? Federal Reserve Board, Finance and Economics Discussion Series Working Paper 2006-09.
- Espey, M. and S. Nair (2005). Automobile fuel economy: What is it worth? *Contemporary Economic Policy* 23(3), 317–323.
- Goldberg, P. K. (1998, March). The effects of the corporate average fuel efficiency standards in the U.S. *The Journal of Industrial Economics* 46(1), 1–33.
- Harrington, W., I. Parry, and M. Walls (2007, June). Automobile externalities and policies. *Journal of Economic Literature* 45, 374–400.
- Jacobson, M. R. (2008, April). Evaluating U.S. fuel economy standards in a model with producer and household heterogeneity. Unpublished.
- Kleit, A. N. (2004, April). Impacts of long-range increases in the fuel economy (CAFE) standard. *Economic Inquiry* 42(2), 279–294.
- Kohn, J. (2000, June 19). GM: Some SUVs to use ethanol. *Automotive News*.
- Liu, Y. (2007). *The Causes and Effects of the Alternative Motor Fuels Act*. Ph. D. thesis, University of Michigan.
- Liu, Y. and G. E. Helfand (2008). The effects of the CAFE standard and incentive program on alternative fuel vehicles and greenhouse gas emissions. Unpublished.
- Morris, M. (2000). *Incentive Zoning: Meeting Urban Design and Affordable Housing Objectives*. APA Planning Advisory Service.
- National Academy of Sciences (2002). *Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards*. Washington, DC: National Academies Press.
- Rosen, S. (1974). Hedonic prices and implicit markets: Product differentiation in pure competition. *Journal of Political Economy* 82(1), 34–55.

- Rubin, J. and P. Leiby (2000). An analysis of alternative fuel credit provisions of U.S. automotive fuel economy standards. *Energy Policy* 13, 589–601.
- Sallee, J. (2007, October). The incidence of tax credits for hybrid vehicles. Unpublished.
- Shepardson, D. (2007, June 20). Auto lobby blitzes senate. *Detroit News*.
- Small, K. A. and K. V. Dender (2007). Fuel efficiency and motor vehicle travel: The declining rebound effect. *Energy Journal* 28(1), 25–51.
- Stern, N. (2006). *Stern Review: The Economics of Climate Change*. Cambridge, MA: Cambridge University Press.
- Tol, R. S. (2005, November). The marginal damage costs of carbon dioxide emissions: an assessment of the uncertainties. *Energy Policy* 33(16), 622–634. 2064-2074.
- U.S. Department of Transportation (2004, October). Automotive fuel economy manufacturing incentives for alternative fueled vehicles. Final Rule.
- U.S. Department of Transportation (2008, April). Corporate average fuel economy for model years 2011–2015 passenger cars and light trucks. Preliminary Regulatory Impact Analysis.
- U.S. Department of Transportation, U.S. Department of Energy, and U.S. Environmental Protection Agency (2002, March). Effects of the alternative motor fuels act CAFE incentives policy. Report to Congress.
- U.S. Environmental Protection Agency (1990, April). Analysis of the economic and environmental effects of ethanol as an automotive fuel. Office of Mobile Sources Special Report.
- Wald, M. L. (2005, November 4). Ford to subsidize ethanol pumps in midwest. *The New York Times*.
- Weiss, M. A. (1992, Spring). Skyscraper zoning: New York’s pioneering role. *Journal of the American Planning Association* 58(2), 201–212.

Weitzman, M. L. (2007, September). A review of *The Stern Review on the Economics of Climate Change*. *Journal of Economic Literature* 45(3), 703–724.

West, S. E. and R. C. I. Williams (2005, May). The cost of reducing gasoline consumption. *The American Economic Review* 95(2), 294–299.

Williams, B. (2008, April 17). Lucerne joins GM's flex-fuel lineup. *Automotive News*.