

CAFE Regulation, New Vehicle Characteristics and Social Welfare*

Thomas Klier
Federal Reserve Bank of Chicago

Joshua Linn
University of Illinois at Chicago

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Abstract

Recent legislation has increased the Corporate Average Fuel Economy (CAFE) standard by 40 percent, which represents the first major increase in the standard since its creation in 1975. Previous analysis of the CAFE standard has focused on short run effects, in which the characteristics of vehicles in the market are fixed, or long run effects, when firms can improve engine technology. This paper focuses on the medium run, in which firms adjust vehicle characteristics without adopting technology. We first show that firms have historically increased fuel efficiency in the medium run by decreasing weight and power. We then simulate the medium run welfare effects of increasing the CAFE standard. To perform the simulation, consumers' willingness-to-pay for weight and power is estimated by a unique identification strategy that takes advantage of variation in the set of engine models used in vehicle models. The estimates imply that an increase in power has an equal effect on vehicle sales as a proportional increase in fuel efficiency. An increase in the CAFE standard reduces producer and consumer surplus in the medium run, and causes substantial welfare transfers across firms.

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

Coinciding with the recent policy debate, a growing literature has analyzed the welfare effects of the CAFE standard and compared the policy to alternatives, such as a gasoline tax. These studies attempt to characterize consumers' and producers' response to an increase in the standard, and how the policy might affect other markets, such as the used vehicles market. In terms of modeling automobile manufacturers' response to the standard, the previous studies can be classified in one of two categories. Some studies (e.g., Goldberg, 1998) have used a short run model, in which vehicle characteristics and technology are held constant, and firms respond to an increase in the CAFE standard by adjusting vehicle prices, i.e., by changing the "sales mix." Other studies use a long run model to estimate the welfare effects of the CAFE standard, in which firms can either adjust the sales mix or adopt new technology (e.g., Kleit, 2004 and Austin and Dinan, 2005). The short and long run analysis find substantial reductions in the welfare of vehicle producers and consumers.¹

¹ Recent work has also investigated consumers' response to the CAFE standard and the distributional effects of the regulation in more detail. Both Bento *et al.* (2006) and Jacobsen (2007) analyze the effects of the regulation on the

Both the short run and long run analysis assume that vehicle characteristics, other than fuel efficiency, remain constant. However, in practice, firms can increase fuel efficiency by decreasing weight and power. For example, removing components or using lighter materials can reduce the vehicle's weight. Furthermore, firms can modify the engine to reduce the number of cylinders that power the vehicle at low speeds, or simply offer additional models with smaller engines. If this approach is less costly than adjusting the sales mix, and allows firms to increase fuel efficiency before new technology is available, it could be an important margin along which firms respond to CAFE. In fact, many industry analysts have suggested that much of the increase in fuel efficiency under the initial standard was caused by decreases in weight and power, and that this trend is likely to continue in the future. Power and weight declined significantly in the late 1970s and early 1980s when the CAFE standard was first introduced. Firms have also begun reducing power to improve fuel efficiency following recent gasoline price increases, and are likely to continue to do so under the new CAFE standard. For example, in the spring of 2008 Honda introduced the 2009 version of its Acura TSX model, which has less power and greater fuel efficiency than the previous model. The vice president of corporate planning for Honda announced at the time of the introduction that "We feel comfortable there's plenty of horsepower already and wanted to focus on improving fuel efficiency and emissions. For us generally, you'll see more of that," (Ohnsman, 2008). Similarly, GM has announced, "Never mind the fuel cells, plug-ins or diesels. To achieve quick improvements in fuel efficiency, General Motors is adopting an off-the-shelf technology: small engines with turbochargers" (Kranz, 2008).

Yet there has not been a systematic analysis of the welfare effects of the CAFE standard using a model in which weight, power and fuel economy are chosen endogenously by firms. In

used vehicles market, and find that incorporating the used vehicle market has significant effects on welfare calculations.

this paper we document the importance of changes in weight and power in the late 1970s and 1980s, following the imposition of the initial standard. We then estimate the effect of a future increase in the standard on social welfare. To do so, we implement a novel identification strategy to estimate consumers' demand for weight and power that accounts for the endogeneity of vehicle characteristics. This paper is thus related to the recent literature on estimating consumer demand when observed product characteristics are endogenous (e.g., Ishii, 2005), but overcomes the additional challenge when unobserved characteristics may also be endogenous.

In this paper, the medium run is defined as the period of time in which engine technology is constant, but firms adjust weight, power and fuel efficiency. In the new vehicle sector, the short, medium and long run arise from the frequency of firms' decisions. Firms typically choose prices and characteristics each year, although large changes in characteristics typically occur every 4-5 years during major model redesigns, and firms can offer price incentives during the year. Engine technologies tend to change more slowly, however. Engines are redesigned at fairly long intervals, roughly every 10 years. Thus, following an increase in CAFE, firms may adjust prices in the short run, weight and power in the medium run, and adopt technology in the long run.

We distinguish the medium and long run response to the CAFE standard in the context of a technology frontier, which represents the maximum fuel efficiency for a given level of engine power and vehicle weight. Firms select a profit-maximizing combination of vehicle characteristics based on the costs and benefits of supplying the characteristics. An increase in the CAFE standard increases the benefit of providing greater fuel efficiency, and firms may increase fuel efficiency at the expense of weight and power.

The recent analysis of the CAFE standard either assumes that firms are fixed at a particular point on the frontier, or that firms can change fuel efficiency by adopting technology that is

represented by a higher frontier. We first argue that firms have historically increased fuel efficiency by reducing weight and power, so that failing to account for this response may lead to incorrect welfare estimates. After the imposition of the first CAFE standards and the large increases in the price of gasoline in the 1970s, U.S. automakers increased the fuel efficiency of their vehicles substantially. We find that changes in power and weight appear to explain most of the improvement in fuel economy during the late 1970s and early 1980s. Subsequently, in the late 1980s and early 1990s, powertrain technology improved gradually, which allowed firms to increase power and weight while keeping fuel efficiency constant.² Greene (1987) and Greene (1991) similarly conclude that short run changes in the sales mix explain a small share of the increase fuel efficiency and that technology explains about half of the increase in fuel efficiency, although the earlier studies do not perform the analysis at the engine level and pertain to a shorter time period.

This paper then analyzes the medium run welfare effects of the CAFE standard, in which firms choose prices and vehicle characteristics, but do not adopt new technology. To calculate the welfare effects of an increase in the standard, it is necessary to estimate the demand for fuel efficiency, power and weight. Most of the literature on vehicle demand (e.g., Berry, Levinsohn and Pakes, 1995) focuses on the endogeneity of vehicle prices, but takes vehicle characteristics as exogenously determined. Using that approach, or performing a simple hedonic analysis, would yield biased estimates of the demand for vehicle characteristics if unobserved characteristics are correlated with observed characteristics.

² A number of studies in the 1980s analyzed the changes in weight, power and fuel efficiency after CAFE was adopted. For example, Greene and Liu (1988) calculate the change in consumer surplus after CAFE was adopted using changes in these characteristics and willingness-to-pay estimates from other studies. These studies did not, however, account for unobserved vehicle characteristics or perform a full welfare analysis.

Only a few studies have estimated consumer demand while accounting for the endogeneity of unobserved product characteristics. Estimation is considerably more difficult than when endogenous characteristics are observed, and requires an identifying assumption on the joint distribution of the unobserved and observed variables. For example, Sweeting (2007) assumes that changes in unobserved characteristics of radio stations occur after the firm has chosen observed characteristics. In this study, we take advantage of the fact that firms often sell models in different vehicle classes with the same engine – for example, the Ford F-Series (pickup truck) and the Ford Excursion (sports utility vehicle, SUV) have the same engine. We use an instrumental variables strategy to estimate consumers' willingness-to-pay for engine power and weight. Combined with previous estimates of the demand for fuel efficiency (Klier and Linn, 2008), the results imply that consumers are willing to pay roughly an equal amount for proportional increases in power and fuel efficiency.

Finally, we use the demand estimates to analyze the medium run welfare effects of the CAFE standard. The preliminary results suggest that it is important to account for endogenous changes in vehicle characteristics. An increase in the CAFE standard would cause large welfare transfers across firms, particularly harming U.S. firms, although the effect is smaller in the medium run than in the short run.

2 DATA

This paper uses a detailed data set of vehicle and engine characteristics and vehicle sales from 1975-2007. Klier and Linn (2008) describe the vehicle characteristics and sales data in more detail. Model sales are from the weekly publication *Wards Automotive Reports* for the 1970s and from *Ward's AutoInfoBank* for the subsequent years. Sales are matched by model from 1975

to 2007 to model characteristics data.³ The characteristics data are available in print in the annual Ward's Automotive Yearbooks (1975-2007), and include wheelbase, curb weight, fuel efficiency and cubic inches of displacement (a measure of engine power).⁴ Note that the data do not include fuel efficiency from 1975-1977, as fuel efficiency was not reported prior to the CAFE standard. We impute fuel efficiency from the other vehicle model characteristics during these years, using the estimated relationship among characteristics for 1978-1980.

The data coverage for cars is far more extensive than for light trucks. The sample includes all car models produced in the U.S. during the 1970s and early 1980s, but does not have any light trucks in the 1970s. Consequently, the analysis in this paper focuses on cars, and it should be noted that cars account for most of the vehicle market during the late 1970s and early 1980s. According to the U.S. EPA (2007), the share of light trucks in the new vehicles market was between 20 and 30 percent between the years 1975 and 1988.

We have obtained data on detailed engine specifications (2000-2007) from CSM, a Michigan-based consulting firm for the automobile sector. The engine data distinguish two levels of aggregation. An engine platform is a broad collection of related engines, while an engine program is defined more narrowly. For example, the Volkswagen Passat and Audi A4 are sold with the same engine program. The Volkswagen Jetta has a different engine program from the Passat and the Audi, but both engine programs belong to the same platform. Firms may produce different versions of the same engine program that vary by power and size. Note that engines in the same program have the same number of cylinders, but the number of cylinders may vary

³ The match is not straightforward because the two data sets are reported at different levels of aggregation. Vehicle characteristics data are reported at the "trim level" to recognize differences in the manufacturer suggested retail price (MSRP); for example, the data distinguish the 2- and 4-door versions of the Honda Accord sedan. We aggregate the characteristics data to match the model-based sales data, and calculate four statistical moments for the distribution of the vehicle characteristics by car line (minimum, maximum, mean and median).

⁴ We are in the process of adding a horsepower variable to the data set, which we will use in the next version of the paper as the preferred measure of engine power throughout; we currently use displacement in much of the analysis.

across engines in a platform. Based on discussions with an industry expert, we assume that the production costs of different versions of the same engine program do not vary significantly.

For each vehicle model, we obtain a list of engine programs that are sold with that model. For a given vehicle model, there are three sources of variation over time in the engines that are sold with the model. First, the engine may be redesigned, which occurs roughly every 10 years, in which case the program code would change. Second, firms may discontinue selling a vehicle model with a particular engine, as Honda recently did with the hybrid Accord. Third, a firm can introduce a new version of the vehicle model that is sold with an engine that had previously been sold only with other vehicle models. We have matched engine and model characteristics for 2000-2007, which limits the estimation of consumer demand for vehicle characteristics to those years; future work will extend the sample to 1995-2007, and possibly further.

3 FUEL EFFICIENCY REGULATION AND ENGINE TECHNOLOGY

3.1 THE CAFE STANDARD

Following the 1973 oil crisis, Congress passed the Energy Policy and Conservation Act in 1975 in order to reduce oil imports.⁵ The Act established the CAFE program and required automobile manufacturers to increase the average fuel efficiency of passenger and non-passenger vehicles sold in the United States to standards of 27.5 miles per gallon (MPG) for passenger cars and 20 MPG for light trucks. The truck standard has gradually increased to 22.5 MPG over the past several years. Firms may also earn credits for over-compliance that can be used in future years. The standards are administered by the U.S. Department of Transportation (DOT) on the basis of the U.S. Environmental Protection Agency's test procedure for measuring fuel efficiency.

⁵ This and the following section rely heavily on National Research Council (2008).

The recently passed Energy Independence and Security Act of 2007 requires DOT to raise fuel-economy standards, starting with model year 2011, until they achieve a combined average fuel efficiency of at least 35 mpg for model year 2020. The CAFE standard continues to be extremely controversial, as the 2007 law has been called “a victory for America” (Senator Carper, D-Del, Stoffer 2007), as well as “unnecessary at best and damaging at worst,” (Wall Street Journal op-ed, Ingrassia 2008).

3.2 PAST AND FUTURE CHANGES IN VEHICLE CHARACTERISTICS

As Section 4 shows in more detail, when the original CAFE standard was introduced, automobile manufacturers rather quickly reduced horsepower and weight in order to raise fuel efficiency. Because fuel efficiency had not been previously regulated in the U.S. market, these strategies allowed nearly full compliance. Over time, engine technologies improved, which allowed firms to improve a vehicle’s performance while continuing to meet the CAFE standard.

Many industry analysts believe that because many of the “easy” adjustments to engine technology were made in response to the initial CAFE standard, the future increase in the standard may be much more costly to producers and consumers. While new powertrain systems, such as those relying on hybrid electric and diesel technologies, have begun to penetrate the U.S. light-duty vehicle fleet, the vast majority of vehicles that make up the fleet are powered by conventional gasoline-powered spark-ignition engines. While essentially every vehicle manufacturer is vying for green credentials by advertising its alternative powertrain research, as of 2007, sales of hybrid vehicles represent about 2% of all light vehicle sales.⁶ Thus, once again,

⁶ In that context it is interesting to note that the hybrids available in the market today represent one of two types: mild hybrids (micro-hybrids, integrated starter-generator hybrids) and parallel hybrids. The Toyota Prius and the GM two-mode hybrid fall into the latter category (National Research Council 2008).

the performance characteristics of the existing gasoline engine technology, as well as the related transmission technologies, are the focus of attention.

Similarly to the 1980s, many firms have recently announced plans to adjust vehicle characteristics in the medium run. Fuel efficiency can be improved by substituting light-weight materials or eliminating features to reduce weight, or by improving the aerodynamic properties of the vehicle. There are also many adjustments to existing engines that would increase fuel efficiency. For example, cylinder deactivation, direct fuel injection, turbocharging and engine downsizing can increase fuel efficiency by at least 7-18 percent with little or no change in production costs (National Research Council, 2008).

3.3 ENGINE TECHNOLOGY FRONTIER

In the following analysis, the term technology frontier refers to a vehicle's maximum fuel efficiency. It is defined as a function of power and weight, holding fixed the engine's cost (and the vehicle's aerodynamic properties). Following Atkinson (1981), the frontier represents the tradeoff between fuel efficiency, power and the vehicle's weight for a given engine technology, as the firm can increase fuel efficiency by decreasing power or weight. Firms may also increase fuel efficiency by adopting new engine technology, such as a continuously variable transmission, which would increase the production cost of the engine, and hence, the vehicle. In this framework, adopting better engine technology would correspond to an outward shift of the engine technology frontier. That is, movement along a frontier corresponds to within-engine program changes in engine characteristics, while a shift of the frontier would require a new engine program.

For a given engine technology, the firm selects the profit-maximizing combination of fuel efficiency, power and vehicle weight. The optimal values of these characteristics depend on consumer demand and production costs; firms equate the marginal costs and benefits of increasing each characteristic. If consumers have a strong preference for power over fuel efficiency, firms will tend to offer larger engines that have lower fuel efficiency. As Section 5 models in more detail, an increase in the CAFE standard increases the benefit of raising fuel efficiency and reducing power and weight. Therefore, an increase in the standard causes a firm to first move along the technology frontier in the direction of greater fuel efficiency and lower power and weight. In the long run, the increased standard may also cause the firm to adopt new engine technology that raises costs but allows the firm to increase fuel efficiency (Austin and Dinan, 2005).

4 THE EFFECT OF WEIGHT AND POWER ON FUEL EFFICIENCY

This section documents changes in fuel efficiency, weight and power in the late 1970s and early 1980s. The analysis shows that historically, changes in weight and power have explained most of the changes in fuel efficiency over a roughly 5-10 year time horizon.

Figures 1 and 2 provide summary information on changes in characteristics in the new vehicles market over time. Figure 1 shows the CAFE standard and changes in weight, power and fuel economy for all cars sold in the U.S. from 1975-2007, using data reported in U.S. EPA (2007). Average fuel efficiency increased dramatically in the late 1970s and early 1980s as the standard was phased in. During the same period, power and weight decreased and then increased.

The following analysis in this section focuses on cars sold by U.S. automobile manufacturers (Chrysler, Ford and GM). As Jacobsen (2007) notes, the CAFE standard has not generally been

binding for Japanese carmakers, particularly Honda and Toyota, while many other firms have paid the fine for not complying with the standard. Some firms, such as Mitsubishi and Nissan, have historically been close to the standard, if slightly above. Sales from such firms account for a small fraction of the total market in the 1980s, however. Consequently, the response of U.S. firms is of particular interest; as noted above, we focus on cars because the data for light trucks are incomplete.

Figure 2 reports the same characteristics as Figure 1, confining the sample to cars sold by U.S. firms. The figure shows that changes in the characteristics of U.S. firms' cars were similar to the overall market.⁷ Starting from 1975, fuel efficiency increased by about 2 MPG by 1978, which was the first year the CAFE standard was in effect. Gasoline prices were fairly stable during this time period, suggesting that the CAFE standard caused the increase, but it should be recalled that fuel efficiency is imputed for 1975-1977, and this result should be treated with caution. From 1978 until the early 1980s, fuel efficiency increased by an additional 4 MPG, during which time the U.S. automakers remained above the standard. From the mid 1980s until the end of the sample period, average fuel efficiency was slightly higher than the standard.

At the same time as fuel efficiency was increasing, weight and power were decreasing. Figure 2a shows that weight decreased by about 1000 pounds between 1975 and 1983, which is about 25 percent of the initial level (Figure 2b). Power decreased by an even greater amount during this period, by about 40 percent. During the late 1980s and early 1990s weight and power increased by about 10 percentage points, while fuel efficiency remained roughly constant (see Figure 2a and 2b). In summary, the increase in fuel efficiency following the imposition of the

⁷ This figure and the following analysis in this section use displacement rather than horsepower. Future work will use horsepower.

CAFE standard coincided with a large decrease in power and a smaller decrease in weight. Over time, however, weight and power increased while fuel efficiency did not change.

The changes in fuel efficiency could be due to changes in the sales mix, the adoption of new engine technology, or movement along the technology frontier due to reductions in weight and power. We first decompose changes in fuel efficiency into the short run changes (sales mix) and medium/long run changes (characteristics and technology). We abstract from entry and exit decisions and analyze a balanced panel of models that have positive sales each year from 1975-1984, which Figure 2 shows to be the main period in which fuel efficiency increased.⁸ The first data series in Figure 3 is the sales-weighted fuel efficiency of the models in the sample, which follows a very similar pattern to Figure 2. Two counterfactual series are constructed for this figure, which decompose the changes in average fuel efficiency into the short run and medium/long run. First, we calculate the sales-weighted average fuel efficiency using the actual sales of the models in each year and the fuel efficiency in 1975; this series illustrates the effect of changes in the sales mix, as an increase in the sales of models that initially have high fuel efficiency would cause the sales-weighted average fuel efficiency to increase. The second series plots average fuel efficiency using the sales weights in 1975 and the actual fuel efficiency of the model each year, which includes medium and long run changes in fuel efficiency.⁹ The constant-MPG series shows that changes in the sales mix increased average fuel efficiency by about 1 MPG between 1977 and 1980, i.e., the first several years of the standard. The average and fixed-

⁸ The models account for about 60 percent of the sales included in the sample in Figure 2.

⁹ Note that there is an additional term in the decomposition of changes in fuel efficiency, where the change in sales-weighted average fuel efficiency equals the sum of the effect of the change in sales mix plus the effect of changes in MPG plus a cross-term: $\Delta \bar{M}_t = \sum_j \Delta s_{jt} M_{j0} + \sum_j s_{j0} \Delta M_{jt} + \sum_j \Delta s_{jt} \Delta M_{jt}$. Figure 2 reports changes in MPG due to changes in MPG and changes in the sales weights, but changes in MPG may also arise if the changes in MPG are correlated with the changes in sales weights, which is the last term in the equation above. In practice, the correlation is fairly small, however. The omitted term in the decomposition explains less than 10 percent of the overall change in all years, and is not shown for clarity.

weight series move together quite closely both before and during the standard, however, implying that within-model changes in fuel efficiency explain most of the overall change. Thus, within the first 10 years of the introduction of the first CAFE standard, firms largely complied by increasing fuel efficiency of the models sold in the market rather than adjusting the sales mix.

Within-model changes in fuel efficiency in Figure 3 could be due to movement along the technology frontier or the adoption of technology that causes an outward shift of the frontier. Unfortunately, sufficiently detailed data are not available for that time period to directly distinguish the two possibilities. Instead, we use more recent engine data to decompose the change in average fuel efficiency in the 1980s into medium and long run changes.

We first estimate the tradeoff between fuel efficiency, weight and power, i.e., the shape of the technology frontier. We use data from 2000-2007 to estimate the following equation:

$$\ln M_{et} = \delta_0 + \delta_1 \ln H_{et} + \delta_2 \ln W_{et} + \eta_e + \varepsilon_{et} \quad (1)$$

The depended variable is the log of the fuel efficiency of engine e in year t and the first two variables are the logs of power and weight. Equation (1) includes engine fixed effects, and the coefficients on power and weight are the within-engine elasticity of fuel efficiency with respect to power and weight. Because firms generally do not adopt new technology within a given engine program, we interpret the coefficients on power and weight as the effect of moving along the engine technology frontier.

Table 1 reports the results of estimating equation (1). The regression includes interactions of the engine program by number of valves by fuel type by engine design (e.g., a separate intercept is estimated for the 24 valve gasoline engine found in the BMW 3 Series). This specification, reported in column 1, defines engines quite narrowly. The estimate implies that firms have some ability to increase fuel efficiency by reducing power; a one percent decrease in power raises fuel

efficiency by 0.07 percent, which is significant at the at the 5 percent level (standard errors are clustered by engine program). The first column also shows that weight has a large effect on fuel efficiency, with an elasticity of -0.41, which is significant at the 1 percent level.

Columns 2 and 3 report similar specifications, replacing the engine interactions with engine program dummies and engine platform dummies (recall that multiple engine programs can be produced on the same platform). The reported coefficients are the within-program and -platform effects of power and weight on fuel efficiency. In column 3, the coefficient on power would be identified, for example, if the firm produces a 4-cylinder engine from a given platform instead of a 6-cylinder engine. Thus, the estimated relationships in columns 2 and 3 include a greater set of modifications the firm might make than in column 1. The elasticities should be larger in magnitude, but the estimate in column 2 is still interpreted as the tradeoff along the technology frontier. The estimate in column 3 may also include shifts of the frontier because engine costs increase with the number of cylinders. In fact, the coefficients are larger, particularly in column 3, which is twice as large as in column 1. On the other hand, the effect of weight on fuel efficiency is the same across specifications, which is as expected, since weight varies at the model level, and not the engine level.

Overall, Table 1 suggests that firms can increase fuel efficiency by decreasing power and weight. Assuming the elasticities have not changed over time, we can use the estimated relationship to isolate the medium run effect of changes in power and weight on fuel efficiency. In particular, we use the actual weight and power each year from 1975-2007 for the sample in Figure 2, combined with the estimates in column 1 of Table 1, to predict the fuel efficiency of each model. Changes in the predicted fuel efficiency correspond to the effect of changes in vehicle characteristics on fuel efficiency, holding technology fixed. The difference between the

actual and predicted series can be interpreted as the effect of new technology on fuel efficiency. Figure 4 reports the actual and predicted fuel efficiency from 1975-2007. The figure demonstrates that decreases in power and weight explain almost half of the increase in fuel efficiency in the late 1970s and early 1980s. By the late 1980s and 1990s, improvements in technology explain most of the overall increase in fuel efficiency since 1975. Similarly, Greene (1987) estimates the technology frontier using vehicle-level data in 1978 and 1985 and concludes that about half of the increase in fuel efficiency was due to technology.

5 ESTIMATING THE VALUE OF FUEL EFFICIENCY AND ENGINE POWER

Section 4 suggests that over about a 5-10 year time horizon, changes in vehicle characteristics explain most of the increase in fuel efficiency in the late 1970s and 1980s. As discussed in the introduction, a similar response is likely to occur following the upcoming increase in the standard. We next analyze the medium run welfare effects of the CAFE standard, i.e., holding vehicle and engine technology fixed but allowing firms to adjust vehicle prices and characteristics. This section specifies and estimates the parameters of the market for new cars, and the following section reports the welfare analysis.

5.1 EMPIRICAL FRAMEWORK

We model the market for new cars, particularly focusing on firms' choices of vehicle characteristics. Consumer demand follows a standard nesting structure. Consumers first decide whether to buy a new vehicle, used vehicle or zero vehicles. If they purchase a new vehicle, they decide whether to buy a car or light truck, and then select a class of cars or trucks, and finally, a

particular vehicle model. The analysis pertains to the car segment of the market, but an analogous model would pertain to the light truck segment.

We begin with a standard nested logit equation for the demand for an individual car model, which can be derived from a utility function that is linear in vehicle model characteristics and price (Berry, 1994). We define three classes based on the vehicle classification system in the Wards database, Small, Medium and Other (McManus, 2005). The market share of each model depends on the price, engine characteristics (e.g., fuel efficiency) and non-engine characteristics (e.g., cabin space) and the model's share of sales in the corresponding vehicle class:

$$\ln s_{jt} - \ln s_{0t} = \alpha P_{jt} + \beta_D D_{jt} + \beta_H H_{jt} + \beta_W W_{jt} + \xi_{jt} + \sigma \ln s_{j|c} \quad (2)$$

The left hand side of equation (2) is the difference between the log market share of model j and the log market share of the outside good, which is a used car; i.e., the denominator of the market shares include cars, light trucks and used vehicles. The first variable on the right hand side is the price of the model, P_{jt} , and the coefficient α is the marginal utility of income. The next three independent variables are expected fuel costs, D_{jt} , power, H_{jt} , and weight, W_{jt} . Following Klier and Linn (2008), we define the variable D_{jt} as dollars-per-mile, equal to the price of gasoline divided by the model's fuel efficiency. The variable is proportional to expected fuel costs if the price of gasoline follows a random walk over the life of the vehicle. Note that the price of gasoline is taken to be exogenous, but the firm can change the expected fuel costs of a model by changing its fuel efficiency. This specification allows power and weight to enter the utility function separately, as opposed to many other studies that use the ratio of power-to-weight, e.g., Petrin (2002).

The next variable in equation (2), ξ_{jt} , is the average utility derived from the vehicle's unobserved characteristics. The final term in equation (2) is the log share of the model's sales in the total sales of the vehicle class, c , where σ is the within-class correlation of market shares.

The supply side of the model is static, following Berry, Levinsohn and Pakes (1995) (henceforth, BLP), but we allow for endogenous vehicle model characteristics. There is a set of multi-product firms in the market that compete in a Bertrand-Nash manner. Each time period firms select the vector of fuel efficiency, weight, power, unobserved characteristics and prices, where the vector X_{jt} includes the fuel efficiency, weight and power of the vehicle. The firm is subject to the CAFE standard, that is to say that the harmonic mean of its fleet's fuel efficiency must exceed a threshold, M . If the firm does not satisfy the constraint it would have to pay a fine, but we assume that in equilibrium the constraint is satisfied exactly; this assumption is relaxed in the estimation and welfare analysis. The firm's optimization problem is:

$$\begin{aligned} \max_{\{p_{jt}, X_{jt}\}_{j \in J_f}} \quad & \sum_{j \in J_f} (p_{jt} - c_{jt}) q_{jt}(p_{jt}, X_{jt}, \xi_{jt}) \\ \text{s.t.} \quad & \frac{\sum_{j \in J_f} q_{jt}(p_{jt}, X_{jt}, \xi_{jt})}{\sum_{j \in J_f} q_{jt}(p_{jt}, X_{jt}, \xi_{jt}) / M_{jt}} \geq M, \end{aligned}$$

where c_{jt} is the marginal cost of the vehicle.

There are several things to note about this setup. First, firms choose the characteristics of each model taking as given the characteristics of the other models in the market and consumer demand. From the first order conditions of the optimization problem, changes in the CAFE constraint may cause firms to change both the observed and unobserved characteristics of their models, as well as prices. Furthermore, via the first order conditions, the observed characteristics are likely to be correlated with the unobserved characteristics of the same vehicle model, and

with both observed and unobserved characteristics of other models. For example, if Honda increases the power of one of its Acura car models, Toyota may increase the fuel efficiency of the Lexus car models, which are in the same class as the Acura.

Second, the coefficient on weight can be positive or negative, as an increase in weight may improve safety but decrease acceleration. Starting from equilibrium, an increase in the CAFE standard raises the benefit of reducing weight (by relaxing the CAFE constraint), and should lead to a reduction in weight.

Finally, both the model's price and the within-class market share depend endogenously on the characteristics and prices of all models. In other words, all of the observed variables in equation (2) are potentially correlated with the unobserved characteristics.

To analyze the medium run welfare effects of the CAFE standard, it is necessary to estimate the parameters in equation (2). Estimating the demand for fuel efficiency, β_D , is straightforward, using the same approach as Klier and Linn (2008). Specifically, we use within model-year variation in gasoline prices and sales to estimate β_D , which controls for unobserved vehicle model-specific parameters, ξ_{jt} . Identification arises from within model-year variation in dollars-per-mile, but it is not possible to estimate the coefficients in equation (2) for which the variables do not vary within the model-year, α , β_H , β_W , and σ . Therefore, we use the estimate of β_D to obtain equation (2')

$$\ln s_{jt} - \ln s_{0t} - \hat{\beta}_D D_{jt} = \alpha P_{jt} + \beta_H H + \beta_W W_{jt} + \xi_{jt} + \sigma \ln s_{jlc} \quad (2')$$

The transformation reduces the number of parameters needed to be estimated. Because of the unobserved parameters, estimating equation (2') by Ordinary Least Squares (OLS) would yield biased estimates of all coefficients. The endogeneity of vehicle characteristics implies that three standard approaches would also yield biased estimates. First, including model fixed effects

would only address the problem if one assumes that the omitted variables do not change over time (i.e., $\xi_{jt} = \xi_j$). In that case, the parameters would be identified by within-model changes in prices, power and weight. This assumption is not appropriate because there are many unobserved characteristics, such as interior cabin space, that firms can change as readily as power and weight.

The second approach would be to follow many previous studies of automobile demand, such as BLP, and use moments of vehicle characteristics of other models in the same class or other models sold by the same firm to instrument for the price and within-class market share. The instruments are valid if characteristics are exogenous, in which case the instruments would be correlated with vehicle prices (via first order conditions from the firm's profit maximization problem), but would not be correlated with the unobserved characteristics. Such an argument cannot be made in the medium run analysis, however, in which characteristics are endogenous. For example, the firm may choose the vehicle's interior cabin space based on its own cost parameters, the length of the vehicle and the length of other vehicles in the same class. Therefore, using the length of other vehicles is not an appropriate instrument for the price and within-class market share of a model because the length instrument is correlated with the model's cabin space. A similar argument can be made for the third approach, performing a hedonic analysis (e.g., McManus, 2005).

5.2 ESTIMATION STRATEGY

We use an estimation strategy that is similar in spirit to Hausman, Leonard and Zona (1994), in that we take advantage of common cost shocks across subsets of the market. The difference is that we use characteristics of other vehicle models to instrument for characteristics and prices,

rather than instrumenting solely for prices, and we exploit the technological relationship across vehicle models sold by the same firm. Many vehicle models contain the same engine as other models sold by the same firm, and models located in different classes often share the same engine. This practice is common for SUVs and pickup trucks, but is not confined to those classes; the following section documents the prevalence of this behavior for cars. As a result, when models in different classes have the same engines, they have very similar engine characteristics. For example, the Ford F-Series, a pickup truck, has the same engine as the Ford Excursion, an SUV, and both models have very similar fuel efficiency and power.

In equilibrium, the power, H_{jc} , of model j in class c depends on the marginal production cost of producing a vehicle with H_{jc} using engine e , $c_e(H_{jc})$, and a class-specific intercept:

$$H_{jc} = c_e(H_{jc}) + \eta_c \quad (3)$$

Consider the power chosen for two models that have the same engine, but belong to different classes. From equation (3), the power of the two models is correlated because they have the same underlying cost function, $c_e(\cdot)$. The class intercepts allow for class-specific demand and supply shocks, so that the power of the two models will differ because of variation across classes in consumer preferences and the characteristics of the other models in the respective classes.

Equation (3) therefore suggests using as instruments in equation (2') the engine and vehicle characteristics of other vehicles with the same engine that are located in different classes. The instrumental variables (IV) approach yields unbiased estimates of the demand for power if the error term in equation (3) is uncorrelated across classes for models that have the same engine.

This assumption is much weaker than the standard assumption that ξ_{jt} is uncorrelated across

vehicle models. Note that estimating equation (2') is preferable to equation (2) because we can use the same set of instruments in either equation, but (2') has one less endogenous variable.¹⁰

5.3 VARIATION IN ENGINES AND FIRST STAGE RESULTS

Before turning to the results of estimating equation (2'), we summarize the extensive engine variation across models and report the first stage estimates for equation (2'). Each row in Table 2 includes a different vehicle class, the first three of which are classes of cars that are included in the estimation sample. The bottom three rows include three classes of light trucks, which are provided for comparison, but are not part of the sample. The first column shows the number of models in 2007 and the second column shows the number of models in the sample. The sample only includes models that have an engine that is used in a model in a different vehicle class, i.e., for which the instruments can be constructed. Thus, only about half of the models are in the sample, but columns 3 and 4 show that the sample includes nearly two-thirds of total car sales. Except for small cars, the sample includes most of the sales for each class. It is important to note that it would be possible to increase the sample size by defining narrower vehicle classes, such as separating large cars from luxury cars. There is a tradeoff between sample size and bias, however, because with narrower classes it is more likely that demand shocks are correlated across classes, invalidating the IV approach.

Table 3 reports summary statistics for the four endogenous right-hand-side variables: vehicle price, power, weight and within-class market share. For the final estimation sample, the two rows of Panel A show the means of the variables, with standard deviations in parentheses (price is

¹⁰ An additional advantage is that power, weight and fuel efficiency are highly correlated with one another, making it difficult to obtain robust estimates of the coefficients on dollars-per-mile, power and weight if all variables are included in the IV estimation.

reported in thousands of dollars, power is measured in horsepower divided by 1000 and weight is in tons).

Panel B reports the first stage estimates. The dependent variables are the four endogenous variables from Panel A. All specifications include firm and year dummies and the reported engine-based instruments. Standard errors are clustered by vehicle model. The estimated coefficients generally have the expected signs and the instruments collectively are strong predictors of the endogenous variables, although the first stage is not as strong for the within-class market share. Note that the weight and within-class share instruments are not strong predictors of the corresponding endogenous variables in columns 3 and 4.

5.4 THE DEMAND FOR POWER AND WEIGHT

Table 4 reports the estimates of the demand for power and weight from equation (2'). The dependent variable is the log of the vehicle model's market share and the independent variables are the price of the vehicle, power, weight, the within-class market share and a set of firm and year dummies, to control for aggregate shocks and unobserved firm variation.

Column 1 reports the OLS estimates of (2') for comparison with the IV estimates. The coefficient on the price of the vehicle is statistically significant but is small in magnitude, as the average own-price elasticity of demand is -0.37. The coefficient on power is negative and significant at the 5 percent level (standard errors are clustered by vehicle model to allow for serial correlation). The sign of the coefficient is the opposite of what is expected, but the estimates in column 1 are probably biased due to unobserved vehicle characteristics. The price coefficient is likely biased towards zero as the price should be positively correlated with

unobserved variables, but the direction of the bias for power and weight is ambiguous because the variables may be positively or negatively correlated with unobserved characteristics.

Previous studies, such as BLP, use observed vehicle characteristics to instrument for the vehicle's price. As noted above, this approach is valid if the instruments are uncorrelated with the unobserved characteristics. Column 2 of Table 4 reports a specification that follows the previous literature and uses other characteristics as instruments, in particular, the sum of the characteristics of other models in the same class and the sum of characteristics of other models sold by the same firm. The coefficient on the vehicle's price is larger in magnitude than the OLS estimate, and implies an average elasticity of demand of -3.0, which is comparable to many previous studies. The coefficients on power and weight are both positive, but power is not statistically significant.

Column 3 reports the baseline specification using the engine-based instruments. The estimated coefficient on the vehicle's price is larger than the OLS estimate, but smaller than the IV estimate in column 2; the average elasticity of demand is about -1.5. The coefficient on power is positive, although it is not statistically significant. The magnitude implies that a one percent increase in power raises willingness-to-pay for the average car by the same amount as a one percent increase in fuel efficiency. Because of the steep tradeoff between power and fuel efficiency shown in Table 1, the estimated demand parameters imply that firms generally maximize the power of a given engine. This result is consistent with Figures 2 and 4, that as engine technology has improved, firms have increased power and weight while keeping fuel efficiency constant.

Columns 4 and 5 are robustness checks. Column 4 replaces power and weight with the ratio of power-to-weight, which is used in many previous studies. As shown below, the point estimate

implies a similar demand for power as in column 3. Finally, column 5 includes additional engine-based instruments, for torque, displacement and the length of the vehicle. The estimates on power and weight are not significantly different from column 3.¹¹

5.5 EFFECT OF CHANGES IN CHARACTERISTICS ON WILLINGNESS-TO-PAY FOR U.S. CARS

If the demand for power is sufficiently large, the decrease in weight and power in the late 1970s and 1980s for U.S. cars would imply that willingness-to-pay for these vehicles decreased. Figure 5 plots the change in willingness-to-pay for the average car sold by U.S. firms from 1975-2007, using the characteristics in Figure 2, the estimates from columns 3 or 4 of Table 4, and holding the price of gasoline fixed. The figure shows that using the estimates from the specification in which power and weight enter separately (column 3 of Table 4), willingness-to-pay decreases slightly but was fairly stable in the early 1980s, when changes in weight and power were most important in terms of improving fuel efficiency. Improvements in engine technology, which were documented earlier, caused willingness-to-pay to increase in the late 1980s and 1990s. Note that the results are sensitive to the coefficient on weight, which has a large standard error in Table 4, and thus there is considerable uncertainty over the willingness-to-pay estimate reported here. The figure also shows that the results are similar using the specification in column 4 of Table 4, in which the power-to-weight ratio enters the utility function, rather than power and weight separately.¹²

¹¹ In column 5 the coefficient on the within-class market share is above 1. That is precluded by theory, although the standard error is large. Consequently, we use the specification in column 3 as the baseline for the remaining analysis.

¹² Greene and Liu (1988) perform a similar analysis and reach the same conclusion using estimates of willingness-to-pay for characteristics from other studies performed in the 1970s and 1980s. In that case and in this paper, the willingness-to-pay calculations would be interpreted as the effect of the CAFE standard on willingness-to-pay only if all characteristics and prices would have remained constant in the absence of the policy. This is extremely unlikely, but we consider Figure 5 to be useful for summarizing the results of estimating equation (2').

6 WELFARE RESULTS AND INTERPRETATION

This section uses the empirical estimates from the model in the previous section to calculate the medium run welfare effects of the CAFE standard. We simulate the equilibrium under a 1 MPG increase in the CAFE standard for cars.

6.1 WELFARE EFFECTS OF AN INCREASE IN THE CAFE STANDARD

In the model used to simulate the equilibrium before and after an increase in the standard, firms maximize profits subject to the standard. Firms choose the price, fuel efficiency, weight and power of the vehicles they sell, taking as given the prices and characteristics of other vehicles in the market. Engine technology is held fixed in the analysis, and each model's fuel efficiency depends on the vehicle's weight and power according to the estimated relationship in column 1 of Table 1. Following Jacobsen (2007) we separate firms into three categories: unconstrained firms, constrained firms, and firms that pay the fine for not meeting the standard. Firms are assigned to the three categories based on past behavior. Honda, Toyota and several smaller Asian firms have consistently exceeded the standard by a wide margin and are unconstrained; Chrysler, Ford and GM, and a few other firms have generally been close to the standard; and all other firms have been well below the standard. In performing the welfare calculations, we assume that firms do not change categories as a result of the increase in the standard, and verify the assumption after simulating the new equilibrium.

Table 5 shows the estimated welfare effects of a 1 MPG increase in the CAFE standard for cars, starting from the equilibrium at the end of the sample period. The columns report the change in consumer surplus and profits (separating constrained and unconstrained firms), the percent change in market share of constrained firms and the overall change in fuel efficiency.

The two rows report the results of different simulations. In the first row, weight and power of each model are held constant while in the second row weight and power are endogenous. The first row thus corresponds to the short run effect of the increase in the standard and the second row to the medium run effect. The medium run results show that an increase in the CAFE standard significantly harms constrained firms. These firms adjust the sales mix and reduce power and weight, which reduces willingness-to-pay for their vehicles. Many consumers who would have otherwise purchased cars made by these firms purchase vehicles sold by unconstrained firms instead. The regulation reduces consumer surplus and profits, particularly for constrained firms. The final column shows that overall fuel efficiency increases by less than the increase in the standard because the constrained firms account for about 60 percent of the market. Comparing the two rows, the short run changes in consumer surplus and profits are considerably larger, showing the importance of accounting for the endogeneity of weight and power in analyzing the welfare effects of the CAFE standard.

6.2 ROBUSTNESS AND LIMITATIONS

We are currently performing additional sensitivity analysis for the estimates of consumers' demand for power. It is important to consider alternative definitions of vehicle classes, assess the validity of the instruments, allow for heterogeneous demand parameters (e.g., separate parameters for each class), and assess the robustness to different functional forms (e.g., including power-to-weight and weight).

The simulations include the assumption that marginal costs do not vary with vehicle characteristics, but a reduction in weight could increase marginal costs. In that case the preceding welfare analysis would overstate the reduction in weight in response to an increase in the

standard. Future work will relax this assumption and estimate the relationship between marginal costs and weight following BLP. More difficult to address is the assumption in the simulations that unobserved characteristics do not change in response to the increase in the standard.

Finally, note that the policy scenario discussed in the previous sections considers the medium run effect of the CAFE standard, holding fixed the set of models in the market. Explicitly allowing for entry and exit of vehicle models would require a dynamic framework and is a potential direction for future research.

7 CONCLUSION

A major increase in the CAFE standard would significantly affect the new vehicles market. This paper analyzes the medium run effect of the standard, which we define as the response when engine technology is held constant, or roughly 5-10 years after an increase in the standard. This paper first shows that firms significantly reduced the power and weight of models sold in the late 1970s and early 1980s in order to increase fuel efficiency, but technological progress caused power to recover in the longer term; average power in 1990 was similar to the level in 1980.

We then estimate consumers' demand for power and weight in order to analyze the medium run welfare effect of the CAFE standard. Estimating demand is complicated by the fact that firms select vehicle characteristics endogenously, which previous empirical work has not addressed. We propose an instrumental variables strategy, which should provide unbiased estimates even in the presence of endogenous and time-varying unobserved characteristics. The preliminary estimates suggest that consumers value an increase in power roughly the same as a proportional increase in fuel efficiency. The estimates also suggest that in terms of willingness-to-pay, the increase in fuel efficiency in the 1970s and 1980s was roughly offset by the decreases in power

and weight. Finally, the welfare calculations suggest that an increase in the CAFE standard causes considerable transfers from constrained firms (U.S. firms, for the most part) to other firms.

8 REFERENCES

- 1 Atkinson, S. (1981). "Rising Gasoline Prices and Federal Automotive Efficiency Standards: Their Impact on Consumer Choice." Research Study #23, American Petroleum Institute, Washington D.C.
- 2 Austin, David and Terry Dinan (2005). "Clearing the Air: The Costs and Consequences of Higher CAFE Standards and Increases in Gasoline Taxes." *Journal of Environmental Economics and Management*: vol. 50, 562-582.
- 3 Bento, Antonio M., Lawrence H. Goulder, Mark R. Jacobsen and Roger H. von Haefen (2006), "Distributional and Efficiency Impacts of Increased U.S. Gasoline Taxes."
- 4 Berry, Steven (1994). "Estimating Discrete Choice Models of Product Differentiation." *RAND Journal of Economics*, vol. 25: 242-262.
- 5 Berry, Steven, James Levinsohn and Ariel Pakes (1995). "Automobile Prices in Market Equilibrium," *Econometrica*: vol. 63(4), 841-890.
- 6 Goldberg, Pinelopi Koujianou (1998), "The Effects of the Corporate Average Fuel Efficiency Standards in the U.S.," *The Journal of Industrial Economics*: vol. 46, n1, 1-33.
- 7 Greene, David L. (1987). "Advances in Automobile Technology and the Market for Fuel Efficiency, 1978-1985." *Transportation Research Record*, vol.1155, 18-27.
- 8 Greene, David L. (1987). "Short-Run Pricing Strategies to Increase Corporate Average Fuel Economy". *Economic Inquiry*, vol. 29, 101-114.
- 9 Greene, David L. and Jin-Tan Liu (1988). "Automotive Fuel Economy Improvements and Consumers' Surplus." *Transportation Research A*, vol. 22-A, 203-218.
- 10 Hausman, Jerry, Gregory Leonard and J. Douglas Zona (1994). "Competitive Analysis with Differentiated Products." *Annales D'Economique et de Statistique*, v34, 159-180.
- 11 Ingrassia, Paul. 2008. "Detroit's (Long) Quest for Fuel Efficiency," *The Wall Street Journal*, February 19, p. A19.
- 12 Ishii, Joy (2005). "Compatibility, Competition and Investment in Network Industries: ATM Networks in the Banking Industry."
- 13 Jacobsen, Mark (2007). "Evaluating Fuel efficiency Standards in a Model with Producer and Household Heterogeneity."
- 14 Kleit, Andrew N. (2004). "Impacts of Long-Range Increases in the Fuel Economy (CAFE) Standard." *Economic Inquiry*, vol. 42, 279-294.
- 15 Klier, Thomas and Joshua Linn (2008). "The Price of Gasoline and the Demand for Fuel Efficiency: Evidence from Monthly New Vehicles Sales Data."
- 16 Kranz, Rick (2008). "GM cars to get smaller engines with turbos," *Automotive News*, <http://www.autonews.com/apps/pbcs.dll/article?AID=/20080128/ANA06/801280366> (accessed January 28 2008).

- 17 McManus, Walter S. (2005). "The Effects of Higher Gasoline Prices on U.S. Vehicle Sales, Prices and Variable Profit by Segment and Manufacturer Group, 2001 and 2004."
- 18 National Research Council - Committee on Assessment of Technologies for Improving Light-Duty Vehicle Fuel efficiency. 2008. Interim Technology Assessment. Letter to national Highway Traffic Safety Administration. February 14
- 19 Ohnsman, Alan. 2008. "Honda bucks industry with TSX favoring fuel efficiency over power," Bloomberg. February 15
- 20 U.S. EPA, 2007. Light-Duty Automotive Technology and Fuel efficiency Trends: 1975 through 2007. EPA 420-R-07-008
- 21 Petrin, Amil (2002). "Quantifying the Benefits of New Products: The Case of the Minivan." *Journal of Political Economy*: vol. 110, 705-729.
- 22 Sweeting, Andrew (2007). "Dynamic Product Repositioning in Differentiated Product Markets: The Case of Format Switching in the Commercial Radio Industry." NBER Working Paper #13522.
- 23 Ward's Automotive Yearbook, 1980-2003, Ward's Communications.
- 24 Ward's AutoInfoBank, Ward's Automotive Group.

Table 1

Within-Engine Tradeoff Between Fuel Efficiency and Power			
	(1)	(2)	(3)
	<u>Dependent Variable: Log Fuel Efficiency</u>		
Log Horsepower	-0.07 (0.03)	-0.08 (0.03)	-0.15 (0.04)
Log Weight	-0.41 (0.07)	-0.44 (0.07)	-0.42 (0.09)
R ²	0.94	0.94	0.89
Number of Observations	1753	1753	1753
Fixed Effects	Engine Program x Characteristics	Engine Program	Engine Platform

Notes: Standard errors in parentheses, clustered by engine. Observations are by engine and year for 2000-2007. All specifications are estimated by Ordinary Least Squares. The dependent variable is the log of the fuel efficiency of the corresponding vehicle model. All columns include the log of the engine's power and the log of the vehicle model's weight. Column 1 includes engine program-cylinder-valve-fuel type-engine design interactions, column 2 includes engine program dummies and column 3 includes engine platform dummies. Columns 2 and 3 also include controls for the number of cylinders, valves, the engine's fuel type, and whether the engine is a hybrid.

Table 2

Sample Coverage by Vehicle Class, 2007

<u>Vehicle Class</u>	<u>Number of Models</u>	<u>Number of Models with Instruments</u>	<u>Fraction Sales</u>	<u>Fraction Sales with Instruments</u>
Small Cars	29	9	0.14	0.05
Mid-Size Cars	33	17	0.22	0.17
Large, Luxury and Specialty Cars	55	30	0.11	0.08
SUVs	69	49	0.27	0.23
Vans	16	7	0.08	0.05
Pickup Trucks	15	10	0.18	0.14
Total	217	122	1.00	0.72

Notes: Vehicles are assigned to the vehicle classes, which are defined in the Wards database. The number of models is the number of unique models in each class in model-year 2007. The number of models with instruments is the number of models for which there is another model that belongs to a different class and has the same engine. Fraction sales is the share of sales of models in the class in total sales in model-year 2007. Fraction sales with instruments is the fraction of sales in total sales for the models with instruments.

Table 3

<u>Summary Statistics and First Stage Results for Cars</u>				
	(1)	(2)	(3)	(4)
	<u>Vehicle Price (thousand dollars)</u>	<u>Power (horsepower/1000)</u>	<u>Weight (tons)</u>	<u>Log Within-Class Share</u>
<u>Panel A: Summary Statistics</u>				
Mean	33.471	194.607	1.683	-3.840
Std Dev	(21.348)	(61.999)	(0.257)	(1.208)
<u>Panel B: First Stage Results</u>				
Vehicle Price	0.513 (0.206)	-0.222 (0.565)	0.000 (0.004)	0.004 (0.018)
Power	0.147 (0.038)	1.130 (0.077)	0.002 (0.001)	-0.007 (0.003)
Weight	1.163 (12.482)	-27.924 (28.249)	0.049 (0.206)	-1.315 (0.935)
Fuel Efficiency	-0.159 (1.048)	1.144 (2.393)	-0.035 (0.017)	-0.049 (0.107)
Log Within-Class Share	-2.539 (2.147)	-7.650 (5.509)	0.027 (0.037)	0.240 (0.208)
R ²	0.75	0.76	0.55	0.25
N	595	595	595	595

Notes: Panel A reports the mean and standard deviation of vehicle price (thousands of dollars), power (horsepower), weight (tons) and the log of the within-class market share. Instruments for vehicle price, power, weight, and within-class market share are constructed from the matched engine model-vehicle model data set. The instruments are the mean of within-class deviations of vehicles belonging to other classes that have the same engine. The sample includes all car models for which the instruments can be calculated, and spans 2000-2007. Panel B reports coefficient estimates with standard errors in parentheses, clustered by model. All regressions include firm-year interactions.

Table 4

The Demand for Power and Weight					
Dependent Variable: Log Market Share					
	(1)	(2)	(3)	(4)	(5)
Vehicle Price	-0.010 (0.003)	-0.070 (0.024)	-0.036 (0.014)	-0.036 (0.013)	-0.028 (0.012)
Power	-1.454 (0.682)	5.218 (3.498)	3.247 (2.401)		4.327 (2.652)
Weight	0.234 (0.184)	1.662 (0.605)	-0.348 (0.738)		-0.053 (0.749)
Power-to-Weight				10.768 (7.982)	
Log Within-Class Share	0.950 (0.026)	0.765 (0.115)		0.784 (0.241)	1.204 (0.279)
R ²	0.94	0.81	0.88	0.89	0.90
N	595	595	595	595	595
Estimation Model	OLS	IV, BLP Demand Instruments	IV, Engine Instruments	IV, Engine Instruments	IV, Engine Instruments

Notes: The table reports the results from estimating equation (2'). Standard errors are in parentheses, clustered by model. The dependent variable is the difference between the log share of sales of the model in total sales, and the log share of sales of used vehicles in total sales, where total sales include used and new vehicles. The independent variables in columns 1, 2, 4 and 5 are the price of the vehicle, in thousands of dollars; power, in horsepower divided by 1000; weight, in tons; the log of the within class share of sales; and a set of firm and year dummies. In column 4 the independent variables are the same, replacing power and weight by the ratio of power to weight. Column 1 is estimated by Ordinary Least Squares and columns 2-5 are estimated by Instrumental Variables. Column 2 instruments for vehicle price using the sum of characteristics of models in the same category produced by other firms and the sum of characteristics of other models produced by the firm. Column 3 uses as instruments the independent variables from Panel B of Table 4. In column 4 the set of instruments also includes power-to-weight. Column 5 includes additional instruments for torque, displacement and the vehicle's length, constructed analogously to the instruments in columns 3 and 4.

Table 5

Welfare Effects of a 1 MPG Increase in the CAFE Standard					
	Change in Consumer Surplus (Million Dollars)	Change in Profits for Constrained Firms (Million Dollars)	Change in Profits for Unconstrained Firms (Million Dollars)	Percent Change in Constrained Market Share	Change in Fuel Efficiency (MPG)
Short Run	-1038.41	-1701.67	497.84	-13.55	0.55
Medium Run	-732.30	-1003.67	144.91	-9.03	0.53

Notes: The table reports the effect of a 1 MPG increase in the CAFE standard on consumer surplus (in millions of dollars), profits of constrained firms (in millions of dollars), profits of unconstrained firms (in millions of dollars), the percent change in market share of constrained firms, and the change in fuel efficiency, in MPG. The two rows report the results of different simulations. In the first row, weight and power of each vehicle model are held constant, while in the second row weight and power are chosen by the firm. The simulations use the model described in Section 5.1 and the estimated parameters from column 3 of Table 4.

Figure 1a: Fuel Efficiency and the CAFE Standard for Cars, 1975-2007

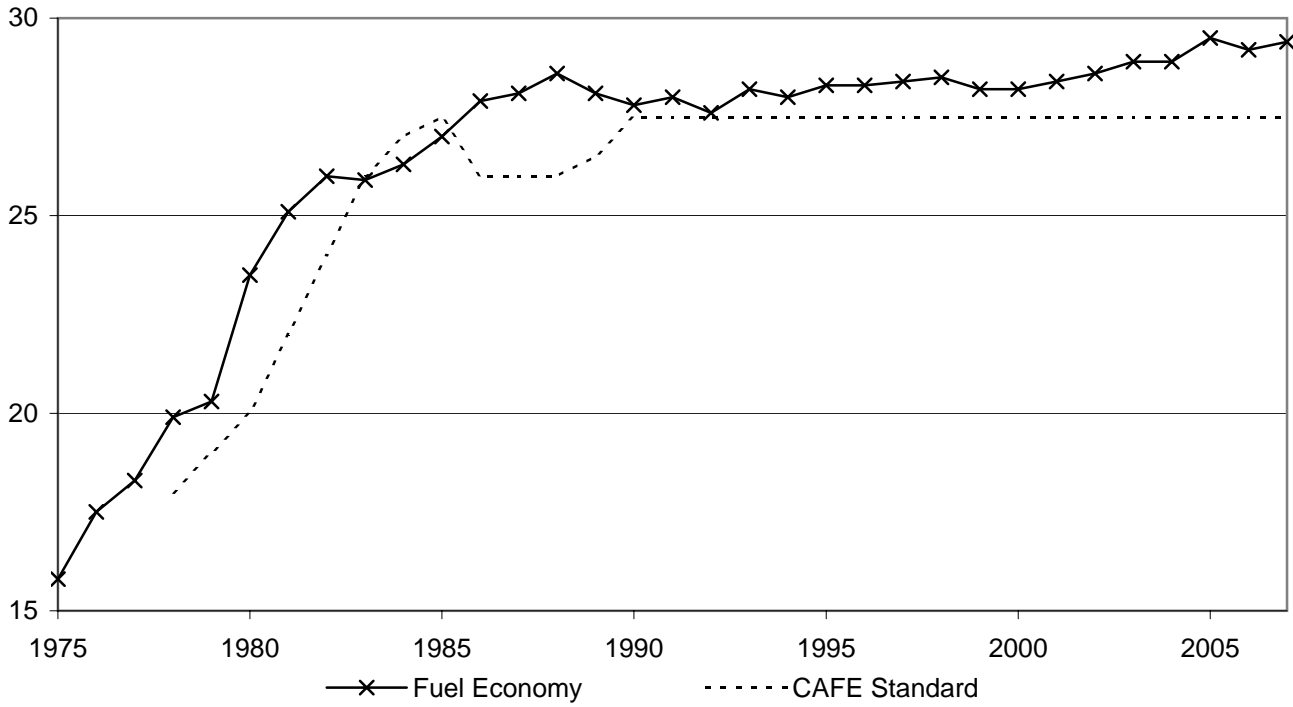


Figure 1b: Power and Weight of Cars, 1975-2007

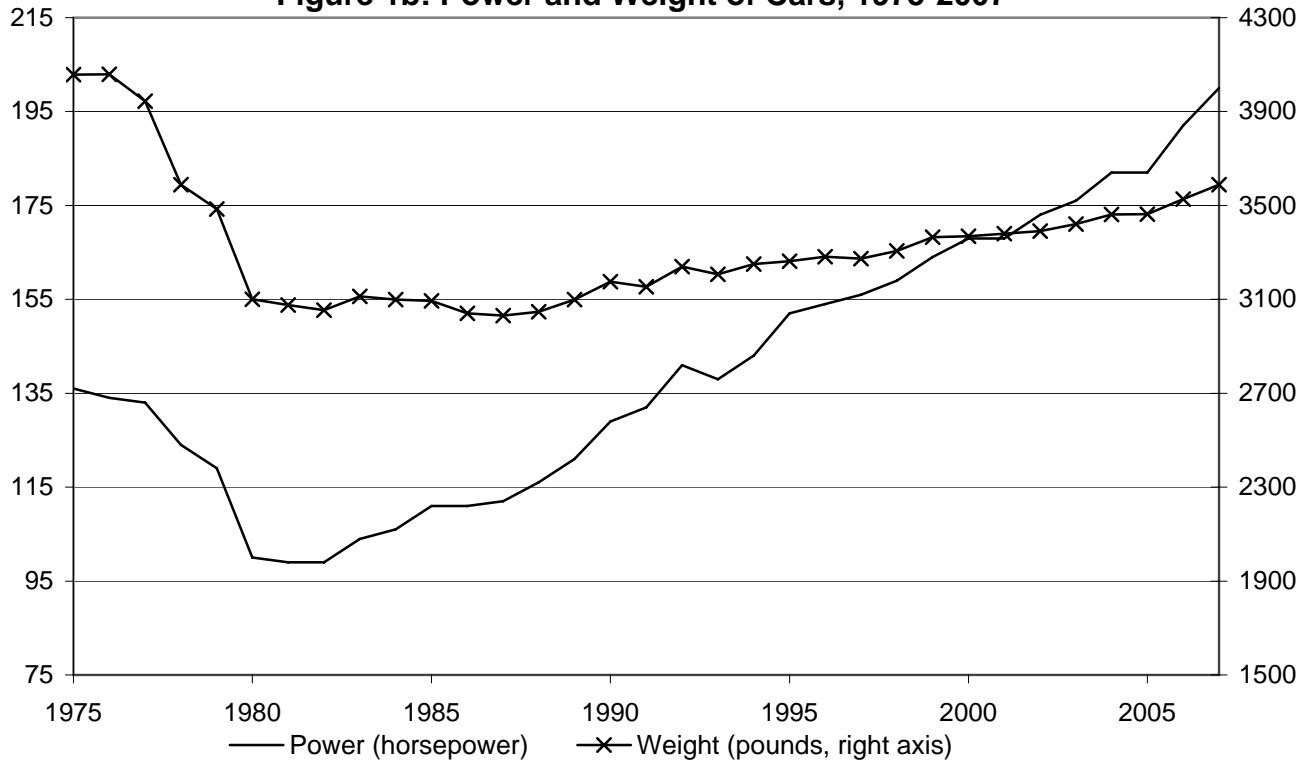


Figure 2a: Fuel Efficiency, Weight and Displacement for Cars of U.S. Manufacturers, 1975-2007

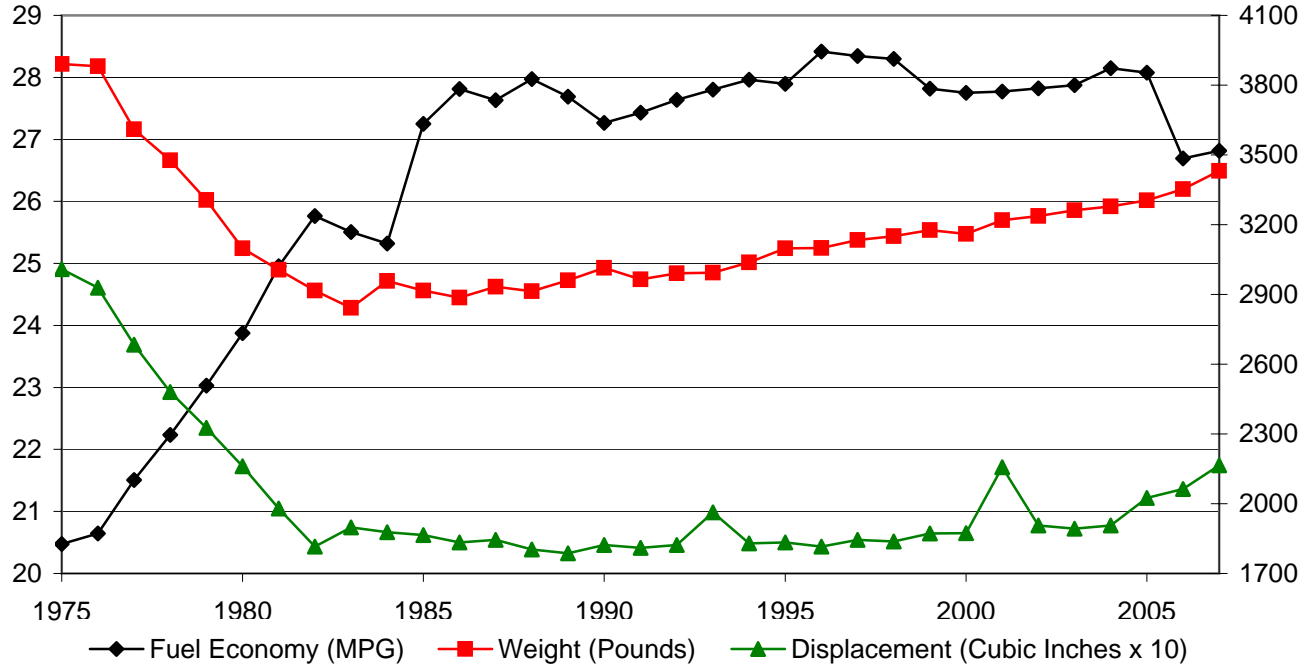


Figure 2b: Percent Change in Fuel Efficiency and Power-to-Weight, 1975-2007

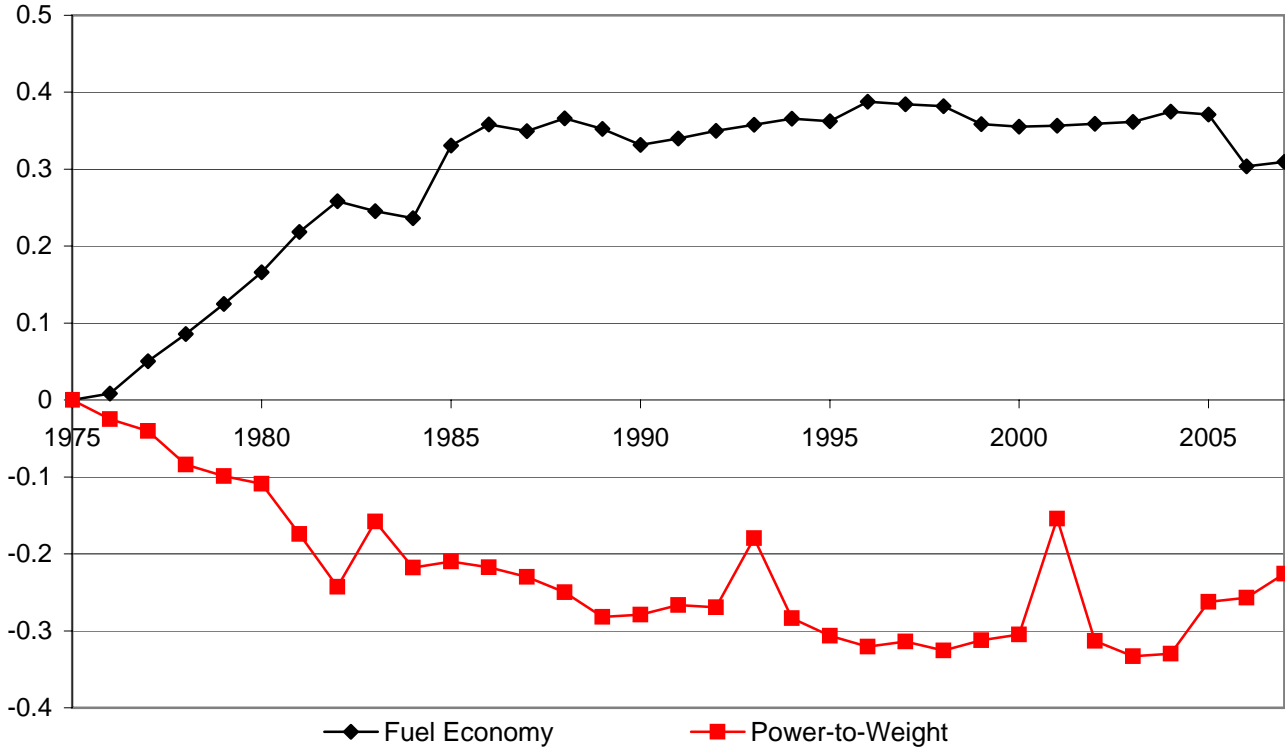


Figure 3: Actual and Counterfactual Fuel Efficiency, Balanced Panel for U.S. Manufacturers, 1975-1984

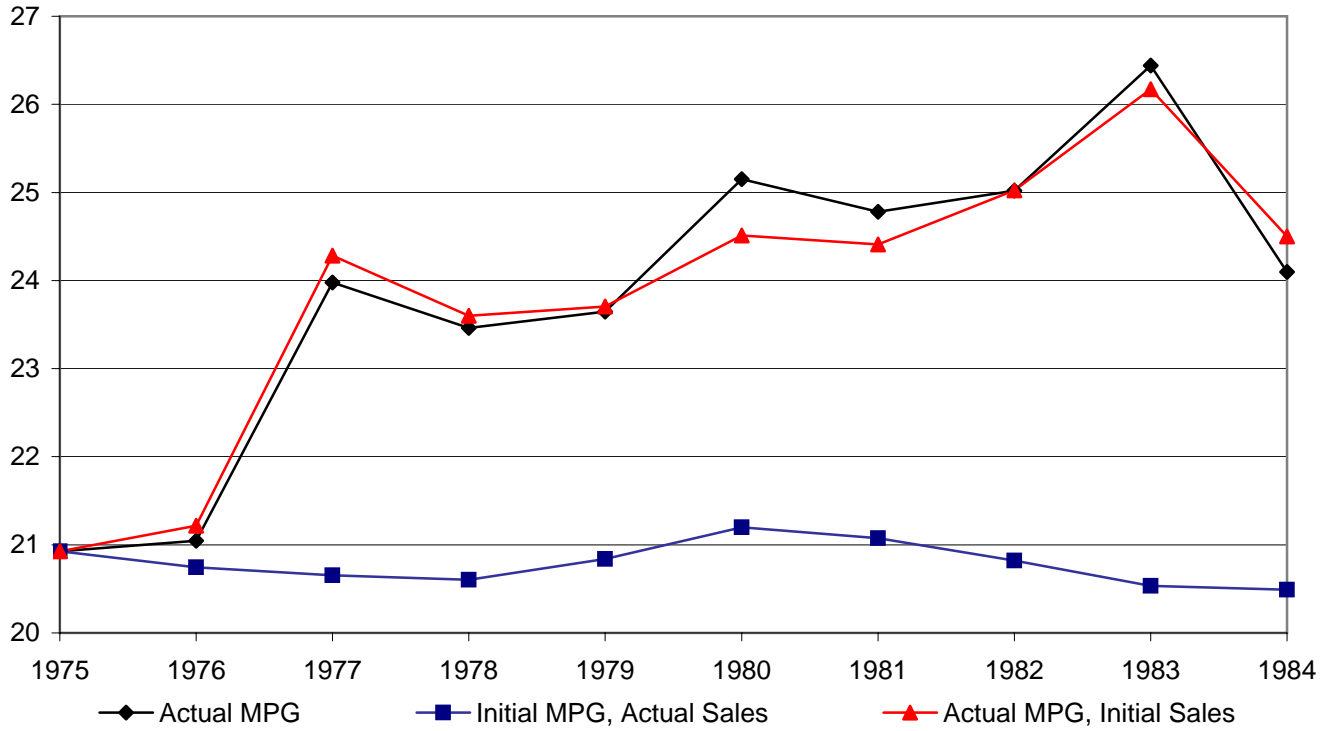


Figure 4: Effect of Power and Weight on Fuel Efficiency for U.S. Manufacturers, 1975-2007

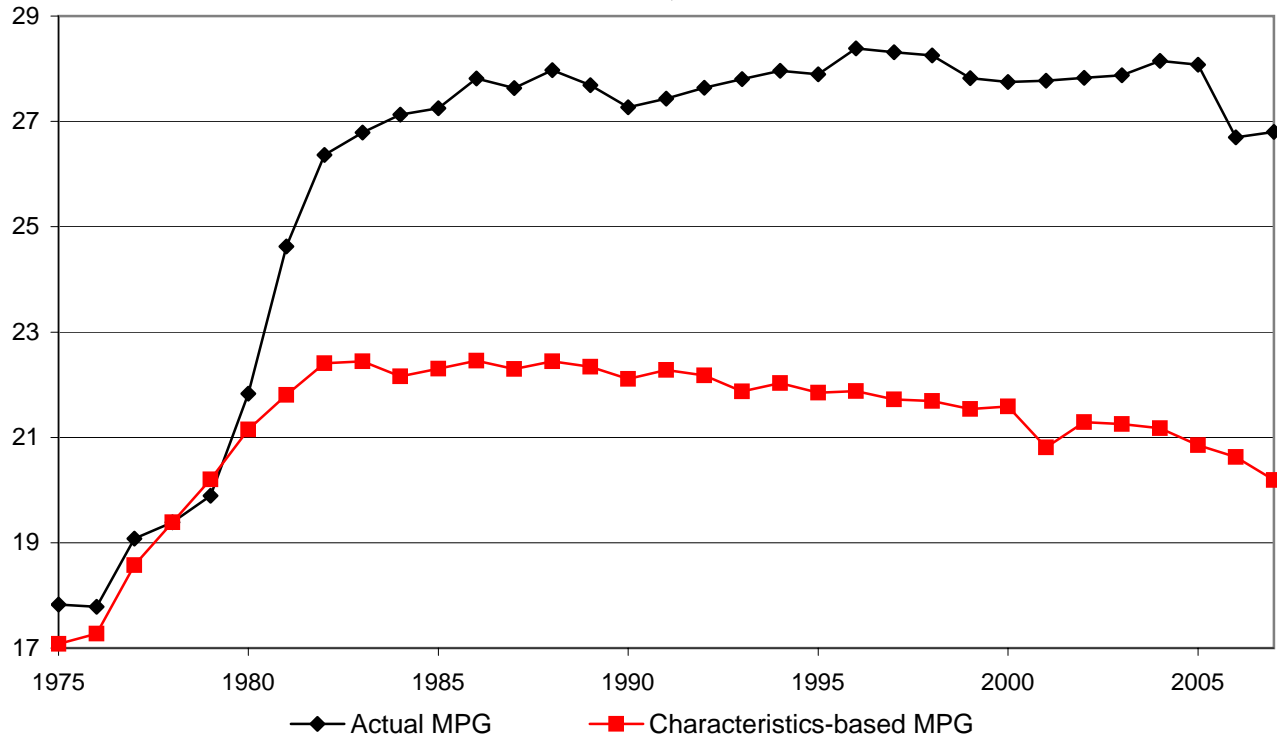


Figure 5: Change in Willingness-to-Pay Due to Changing Vehicle Characteristics for U.S. Firms, 1975-2007

