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

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PRELIMINARY AND INCOMPLETE

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 the short run effects, in which vehicle characteristics are held fixed, or the long run, when firms can adopt new power train technology. This paper focuses on the medium run, when firms can choose characteristics such as weight and power, and have a limited ability to adopt technology. We first document the historical importance of the medium run and then estimate consumers' willingness-to-pay for fuel efficiency, power and weight. We employ a unique empirical strategy that accounts for the characteristics' endogeneity, which has not been addressed in the literature, by using variation in the set of engine models used in vehicle models. The results imply that an increase in power has an equal effect on vehicle sales as a proportional increase in fuel efficiency. We then simulate the medium run effects of an increase in the CAFE standard. The policy reduces producer and consumer welfare and causes substantial transfers across firms, but the effects are significantly smaller than in previous studies.

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1 INTRODUCTION

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

Coinciding with the recent policy debate, a sizeable literature has analyzed the costs of the CAFE standard to consumers and producers of new vehicles. These studies can be classified into two categories. Some, including 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, such as Austin and Dinan (2005), use a long run model to estimate the costs of the CAFE standard, in which firms choose vehicle prices and power train (engine and transmission) technology.

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

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

This paper contributes to the literature on the CAFE standard as the first to characterize the medium run effects of the regulation, in which firms choose weight and power and can adopt a limited set of technologies. The analysis is therefore related to the recent literature on endogenous product characteristics (e.g., Ishii, 2005 and Sweeting, 2007). As with other studies with endogenous product characteristics, a major challenge is to consistently estimate consumer demand for characteristics that accounts for their endogeneity. We accomplish this using a unique data set and identification strategy that exploits variation in the set of engines sold in vehicle models.

We first document the importance of changes in weight and power following the imposition of the initial CAFE standard in 1978. Changes in the sales mix reduced fuel efficiency by a small amount and for only a few years after the standard was imposed. Reductions in weight and power explain much of the increase in fuel efficiency in the late 1970s and early 1980s, after which technology adoption becomes increasingly important. These patterns suggest that the medium run response to CAFE lasts about 5 years, which is consistent with the time frame in which firms typically redesign power train technology.[1] The importance of medium run changes, relative to the short run, suggests that the short run analysis may overestimate costs by a wide margin.

[1] A number of studies in the 1980s analyzed the changes in weight, power and fuel efficiency after CAFE was adopted. Similarly to this study, Greene (1987 and 1991) concludes that short run changes in the sales mix explain a small share of the increase 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, as we do, and pertain to a shorter time period. 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 results motivate the main part of the paper, in which we compare the short and medium run costs of the CAFE standard. In the medium run, firms choose vehicle prices and characteristics but cannot change the power train technology. The most significant challenge to this exercise is the need to account for the endogeneity of product characteristics when estimating consumer demand, which has been ignored in the large literature on consumer demand in the new vehicles market. For example, Berry, Levinsohn and Pakes (1995) construct a set of instrumental variables that is valid only if observed characteristics are uncorrelated with unobserved characteristics, which seems unlikely to be the case; for example, a larger vehicle may have worse handling.

A few studies of other industries have estimated consumer demand when observed product characteristics are endogenous (e.g., Ishii, 2005), but the new vehicles market poses the additional challenge that unobserved characteristics are also endogenous and are potentially correlated with observed characteristics. In this case, estimation requires an identifying assumption on the joint distribution of the observed and unobserved variables. For example, Sweeting (2007) assumes that changes in unobserved characteristics of radio stations occur after the firm has chosen the observed characteristics. We exploit a particular feature of the new vehicles market: the fact that firms often sell models in different vehicle classes with the same engine. For example, the Ford F-Series (a pickup truck) and the Ford Excursion (a sports utility vehicle) have the same engine. We use this variation to estimate consumers' willingness-to-pay for engine power and weight by employing an instrumental variables strategy that is similar to Hausman *et al*. (1994). 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.

We use the empirical estimates to simulate the medium run cost of the CAFE standard. Similarly to the short run analysis, an increase in the CAFE standard would cause large transfers across firms and would particularly harm U.S. firms in the medium run. However, the medium run costs are about one-half of the short run costs, which implies that the short run analysis significantly overestimates costs for the first 10 years after a change in the standard. Furthermore, the long run analysis does not reveal the substantial improvements in fuel efficiency that can be attained only a few years after a new standard is adopted.

2 DATA

This paper uses a detailed data set of vehicle and engine characteristics and vehicle sales from 1975-2008. Klier and Linn (2008) describe the vehicle characteristics and sales data in more detail. 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 to vehicle characteristics by model from 1975-2008.[2] The characteristics data are available in print in the annual Ward's Automotive Yearbooks (1975-2008), and include horsepower, curb weight, length and fuel efficiency. 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 1978-1979.

The data coverage for cars is far more extensive than for light trucks. The sample includes all car models produced in the U.S. during the 1970s, but does not have any light trucks in the

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

1970s. Consequently, the historical analysis in this paper focuses on cars, which account for most of the vehicle market during the late 1970s and early 1980s. According to the U.S. EPA (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 (2000-2008) 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 across engines in a platform.

For each vehicle model, we construct a list of engine programs that are sold with that model. For a given vehicle model, there are three sources of variation over time in the engine technologies that are sold with the model. First, the engine may be redesigned, which occurs roughly every 10 years, in which case the program identifier changes. Second, firms may discontinue selling a vehicle model with a particular engine, as Honda recently did with the hybrid Accord. Third, a firm can introduce a new version of the vehicle model that is sold with an engine that had previously been sold only with other vehicle models. We have matched engine and model characteristics for 2000-2008, which limits the estimation of consumer demand for vehicle characteristics to those years; future work will extend the sample to 1995-2008, and possibly further.

3 Fuel efficiency Regulation and Engine Technology

3.1 The CAFE Standard

Following the 1973 oil crisis, Congress passed the Energy Policy and Conservation Act in 1975 in order to reduce oil imports.[3] The Act established the CAFE program and required automobile manufacturers to increase the average fuel efficiency of passenger and non-passenger vehicles sold in the United States. There are separate standards for cars and light trucks, which have varied slightly over time; for model-year 2007, the standards are 27.5 miles per gallon (MPG) for cars and 22.2 MPG for light trucks. Firms may also earn credits for over-compliance that can be used in future years. The standards are administered by the U.S. Department of Transportation (DOT) on the basis of the U.S. Environmental Protection Agency's test procedure for measuring fuel efficiency.

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

3.2 CAFE and Market Outlook

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

[3] This section draws extensively from National Research Council (2008).

Because fuel efficiency had not been previously regulated in the U.S. market, these strategies allowed nearly full compliance. Engine technologies improved over time, which allowed firms to improve a vehicle's performance while continuing to meet the CAFE standard.

Many industry analysts believe that because many of the "easy" 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. market, 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 advertising its alternative powertrain research, as of 2007, sales of hybrid vehicles represent about 2% of total sales of cars and light trucks.[4] Thus, once again, the performance characteristics of the existing gasoline engine technology, as well as the related transmission technologies, are the focus of attention.

3.3 The Medium Run

To clarify the difference between this study and previous research, we define the medium run as the period of time in which engine technology is constant, but firms can adjust weight, power and fuel efficiency. In the new vehicle sector, the short, medium and long run arise from the timing of firms' major decisions. Firms typically choose vehicle prices each year, although firms can offer price incentives during the year. Large changes in vehicle characteristics typically occur every 4-5 years during major model redesigns. Engine technologies change more slowly, as engines are redesigned roughly every 10 years. Thus, following an increase in the CAFE

[4] 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).

standard, firms may adjust prices in the short run; weight, power and fuel efficiency in the medium run; and power train technology in the long run.

More specifically, the medium run includes two types of modifications to the vehicle model. First, the firm may improve fuel efficiency by reducing weight or power. Using lighter weight components or replacing a six-cylinder engine with a four-cylinder engine would increase fuel efficiency. Note that the former change would likely increase production costs while the latter change might increase costs; we return to this issue in Section 6.

The second type of modification is that there is a limited set of technologies that the firm can adopt without redesigning the engine or transmission. Engines are intentionally designed with such flexibility to allow firms to respond to demand shocks without completely redesigning the power train. For example, a 4-speed automatic transmission can be replaced by a 5-speed transmission, which increases fuel efficiency by about 6 percent but does not require the engine to be redesigned. On the other hand, it is necessary to redesign the power train to install a continuously variable transmission, which improves fuel efficiency by up to 10 percent (NHTSA, 2008).

In the medium run, the firm selects the profit-maximizing combination of fuel efficiency, power and weight. 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 or reducing power and weight. Because the firm has greater flexibility to adopt engine technology in the long run, the long run improvement in technology is likely to be greater than the medium run (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. Historically, much of the increase in fuel efficiency during the 5-10 years following the imposition of the initial standard was due to changes in weight and power. This result motivates the use of a medium run model to simulate the effect of the CAFE standard in the following sections.

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 efficiency for all cars sold in the U.S. from 1975-2007, using data reported in U.S. EPA (2007). Average fuel efficiency increased dramatically in the late 1970s and early 1980s as the standard was phased in. During the same period, power and weight decreased and then increased.

The analysis in this section focuses on cars sold by U.S. automobile manufacturers (Chrysler, Ford and GM) for two reasons. First, as Jacobsen (2008) notes, there have been three categories of firms: firms that consistently exceed the standard by a large amount (e.g., Honda and Toyota); firms that are very close to the standard (e.g., Ford); and firms that consistently pay a fine for not meeting the standard. U.S. firms account for the vast majority of sales from the second, constrained, category, so the response of U.S. firms to the CAFE standard is of particular interest. Second, the light truck data are incomplete, and do not allow for a complete analysis for trucks in the 1970s and 1980s.

Figure 2 reports the same characteristics as Figure 1 but confines 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. Between 1975 and 1978, which was the first year the CAFE standard was in effect, fuel efficiency increased by about 2 MPG. Gasoline prices were fairly stable during this time period, suggesting that the increase was in anticipation of the standard. It should be recalled, however, that fuel efficiency 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 1982, which is about 25 percent of the initial level (Figure 2b). Power decreased by about the same percentage during this period. During the late 1980s and early 1990s weight and, particularly, power increased while fuel efficiency remained roughly constant (see Figure 2a and 2b). In summary, the increase in fuel efficiency following the imposition of the CAFE standard coincided with a large decrease in power and weight. Over time, however, weight and power increased while fuel efficiency did not change.

The changes in fuel efficiency could be due to short run changes in the sales mix; medium run changes in power, weight or technology; or the long run adoption of power train technology. We first separate the short run from the medium and long run. We abstract from entry and exit decisions and analyze a balanced panel of models that have positive sales each year from 1975-1984, which Figure 2 shows to be the main period in which fuel efficiency increased.[5] 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 separate the short run changes in average fuel efficiency from the medium and long run. The first series is the sales-weighted average fuel efficiency, which is calculated using the actual sales of the models in each year and the fuel efficiency in 1975; this series illustrates the

[5] The models account for about 45 percent of the sales included in the sample in Figure 2.

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.[6] The short run series shows that changes in the sales mix increased average fuel efficiency by about 0.5 MPG between 1978 and 1981. The other counterfactual series is very close to the average MPG, however, implying that within-model changes in fuel efficiency explain nearly all of the overall change. Thus, within the first 10 years of the introduction of the CAFE standard, firms largely complied by increasing fuel efficiency rather than adjusting the sales mix.

Within-model changes in fuel efficiency in Figure 3 could be due to medium or long run changes in vehicle characteristics and technology. Recall that there are two types of medium run changes: reductions in weight or power and the adoption of fuel efficiency-improving technology. Unfortunately, sufficiently detailed data are not available for that time period to directly distinguish medium and long run technology adoption, but we can document the importance of changes in weight and power and provide a lower bound to the medium run response.

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

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

[6] 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: $\Delta \overline{M}_t = \sum_j \Delta s_{jt} M_{j0} + \sum_j s_{j0} \Delta M_{jt} + \sum_j \Delta s_{jt} \Delta M_{jt}$. 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.

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

Table 1 reports the results of estimating equation (1). The two columns include engine program and engine platform fixed effects (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. The two specifications should be considered to be lower and upper bounds of the medium run effect of weight and power on fuel efficiency, holding fixed engine technology. The within-program elasticity of fuel efficiency with respect to power is -0.07 and for weight is -0.33; the estimate for power is larger in column 2 with platform fixed effects. On the other hand, the effect of weight on fuel efficiency is the same, which is as expected because weight varies at the 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 obtain a lower bound of 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. A change in weight or power would cause a change in predicted fuel efficiency. The predicted series captures medium run changes in weight and power, but does not include medium run technology adoption. The difference between the actual and predicted series can be interpreted as the effect on fuel efficiency of medium and long run technology adoption. Figure 4 reports the actual and predicted fuel efficiency from 1975-2007. The figure demonstrates that decreases in power and weight explain about one-third of the increase in fuel efficiency in the late 1970s and early 1980s.[7] Given that this is probably a lower bound, we conclude that the medium run response to the CAFE standard has been historically important

5 Estimating the Value of Fuel Efficiency and Engine Power

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

5.1 The New Vehicles Market

We model the market for new vehicles, particularly focusing on firms' choices of vehicle characteristics. The model is static and in each period firms select vehicle prices and characteristics for the models they sell. Consumer demand for each model depends on its price and characteristics, and each period there is a market clearing vector of prices and quantities.

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

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

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 vehicle; the denominator includes new 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

[7] Similarly, Greene (1987) concludes that about half of the increase in fuel efficiency between 1978 and 1985 was due to technology.

fuel costs, D_{jt}, the ratio of power to weight (a proxy for acceleration), HW_{jt}, and weight, W_{jt}. Similarly to Klier and Linn (2008), we define the variable D_{jt} as dollars-per-mile, which is equal to the price of gasoline divided by the 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-to-weight and weight to enter the utility function separately, while many other studies omit weight, e.g., Petrin (2002).

The next term in equation (2), 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). A set of multi-product firms competes in a Bertrand-Nash manner. Each firm is subject to the CAFE standard, that the harmonic mean of its car and truck fleets must exceed particular thresholds. If the firm does not satisfy the constraint it would have to pay a fine, but we assume that in equilibrium the constraint is satisfied exactly; this assumption is not important for the empirical analysis and is relaxed in the simulations.

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

$$\max_{\{p_t\}_{j\in J_f}} \sum_{j\in J_f} (p_{jt} - c(X_{jt}))q_{jt}(p_{jt}, X_{jt}, \xi_{jt}) \tag{SR}$$

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

where X_{jt} is a vector of (exogenous) characteristics: fuel efficiency, weight and power; and $c(X_{jt})$ is the marginal cost of the vehicle, which depends on the characteristics. The parameter C_{jt} is the CAFE standard that applies to model j in year t. For example, the standard for cars and light trucks in model-year 2007 is 27.5 and 22.2 MPG. Under the new CAFE framework that begins with model-year 2011, C_{jt} depends on the vehicle's footprint and whether it is a car or light truck.

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

$$\max_{\{p_t, X_{jt}, T_{jt}\}_{j\in J_f}} \sum_{j\in J_f} (p_{jt} - c(X_{jt})) q_{jt}(p_{jt}, X_{jt}, \xi_{jt}) \tag{MR}$$

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

$$\ln M_{jt} = \delta_0 + \delta_1 \ln H_{jt} + \delta_2 \ln W_{jt} + T_{jt} \tag{b}$$

$$\ln c_{jt} = \gamma_0 + \gamma_1 \ln H_{jt} + \gamma_2 \ln W_{jt} + \gamma_3 \ln T_{jt} \tag{c}$$

Equation (b) specifies that the fuel efficiency of vehicle model j depends on the engine's horsepower, the vehicle's weight and the level of the engine technology. The engine technology is continuous and is scaled so that a unit increase raises log fuel efficiency by one.[8] The marginal cost of the vehicle model is given by equation (c) above, and depends on the power of the engine, the weight of the vehicle and the engine technology. Note that improving engine technology raises fuel efficiency and therefore demand for the model, but also raises costs; this

[8] The subscripts for equation (b) is different from equation (1) above. Equation (1) is estimated using observations at the engine-model level. Sales data are only available at the engine level, however, so the model and empirical analysis in this section is aggregated to the model level.

tradeoff is governed by the coefficient on dollars-per-mile in equation (2) and the cost elasticity given above. Similar tradeoffs exist for weight and power.

To simulate the medium run costs 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 fuel costs, but it is not possible to use this approach to estimate the coefficients in equation (2) for the variables that 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'):

$$\ln s_{jt} - \ln s_{0t} - \hat{\beta}_D D_{jt} = \alpha P_{jt} + \beta_H HW_{jt} + \beta_W W_{jt} + \xi_{jt} + \sigma \ln s_{j|c} \qquad (2')$$

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

From a modeling perspective, optimization problem (MR) is a straightforward extension of the standard setup with exogenous characteristics, (SR). Allowing for endogenous characteristics has a major empirical implication, however. Firms choose the characteristics of each model, taking as given the characteristics of the other models in the market. From the first order conditions for (MR), the observed characteristics are correlated with the unobserved characteristics of the same vehicle model, and with both observed and unobserved characteristics of other 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 close substitutes to the Acura.

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 unobserved 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 (an unobserved variable) based on the cabin space and length of competing models. 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 unobserved 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 *et al*. (1994), in that we take advantage of common cost shocks across subsets of the market. The difference is that we use characteristics of other vehicle models to instrument for characteristics and prices, rather than instrumenting solely for prices, and we exploit the technological 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 across the entire market. 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.

Consider two vehicle models, j and j', which have engines e and e' in the same engine program. The models belong to different vehicle classes and in equilibrium, the optimal power of model j depends on the cost of increasing power for the particular engine program, and similarly for model j'. Therefore, the power of model j will be a function of the power of model j', plus a constant:

$$H_{je} = f(H_{j'e'}) + \eta_c \tag{3}$$

The power of the two models is correlated because they have the same engine. The class intercepts, η_c, 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.[9] This assumption is much weaker than the standard assumption that observed and unobserved characteristics are uncorrelated.[10]

5.3 Variation in Engines and First Stage Results

Before reporting the results of estimating equation (2'), we summarize the engine variation across models and discuss the first stage estimates for equation (2'). Each row in Table 2 includes a different vehicle class. Column 1 shows the number of models in 2008 and column 2 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. Only about two-thirds of the models are in the sample, but columns 3 and 4 show that the sample includes about 80 percent of total sales. Furthermore, 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 in equation (2'): vehicle price, power-to-weight, 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

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

[10] Estimating equation (2') is preferable to equation (2) because the same set of instruments is available for both equations, but (2') has one less endogenous variable. An additional advantage is that power, weight and fuel efficiency are highly correlated with one another, making it difficult to obtain robust estimates of the coefficients on dollars-per-mile, power and weight if all variables are included in the IV estimation.

deviations in parentheses (price is reported in thousands of dollars, power-to-weight is measured in horsepower per pound and weight is in tons).

Panel B reports the first stage estimates. The dependent variables are the endogenous variables from Panel A. All specifications include firm-year interactions and the reported engine-based instruments. The estimated coefficients generally have the expected signs and the instruments are jointly strong predictors of the endogenous variables (note that the first stage is not as strong for the within-class market share).

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-to-weight, weight, the within-class market share and a set of firm-year interactions, to control for firm-year shocks.

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 -0.3. The coefficient on power-to-weight is negative and is not significant. The price coefficient is likely biased towards zero because the price should be positively correlated with unobserved variables, but the direction of the bias for the characteristics is ambiguous because they may be positively or negatively correlated with unobserved characteristics.

Previous studies, such as BLP, use observed vehicle characteristics to instrument for the vehicle's price. As noted above, this approach is only valid if the instruments are uncorrelated with the unobserved characteristics. Column 2 of Table 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 -1.7, which is somewhat smaller than previous studies. The coefficient on power-to-weight is positive and is larger than in column 1.

Column 3 reports the baseline specification using the engine-based instruments. The estimated coefficient on the vehicle's price is larger than the other estimates and the average elasticity of demand is about -2.6. The coefficient on power-to-weight is about the same magnitude as column 2, although it is not statistically significant. The estimate implies that a one percent increase in power raises willingness-to-pay for the average vehicle 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 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.

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

If the demand for weight and power is sufficiently large relative to the demand for fuel efficiency, the decrease in weight and power in the late 1970s and 1980s for U.S. cars would 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 column 3 of Table 4, and holding the price of gasoline fixed. The figure shows that willingness-to-pay decreased soon after CAFE was implemented, but increases steadily beginning around 1980.[11] Note that the willingness-to-pay calculations are properly interpreted as the effect of the CAFE standard on willingness-to-pay only if all characteristics and prices would have remained constant in the absence of the policy. Thus, Figure 5 does not allow for any inference about the causal effect of CAFE, but is useful for summarizing the results of estimating equation (2').

6 Simulation Results and Interpretation

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

6.1 Short Run Costs of an Increase in the CAFE Standard

In the simulation model firms maximize profits subject to the CAFE standard. For comparison with the previous literature and with the medium run analysis, we first simulate the short run effects of the CAFE standard. Specifically, firms choose a vector of prices to maximize profits subject to the CAFE standard. As before, firms are separated into three categories: unconstrained firms that exceed the standard, constrained firms that meet the standard, and firms that pay the fine for not meeting the standard. Firms are assigned to the three categories based on past behavior. Honda, Toyota and several smaller Asian firms have consistently exceeded the standard by a wide margin and are unconstrained; Chrysler, Ford and GM and a few other firms have generally been close to the standard and are constrained; and all other firms have been well below the standard. The constrained firms solve problem (SR), while the other firms do not have a constraint; unconstrained firms that do not satisfy the constraint pay a fine. In performing the

[11] 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.

simulations, 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 effects of a 2 MPG increase in the CAFE standard. The columns report the changes in consumer surplus, total profits, profits of U.S. firms, market share of U.S. firms, overall fuel efficiency, horsepower and weight. Consumer surplus declines by about $9 billion because of the changes in vehicle prices under the increased standard. Total profits decrease by about $13 billion. Columns 3-5 show that the increase in the standard causes a transfer in profits from U.S firms to Honda and Toyota, which can be explained as follows. In response to the higher CAFE standard, U.S. firms must change their sales mix in order to increase average fuel efficiency. The resulting price changes cause consumers to substitute to competing vehicle models, which increases the profits of firms that are not constrained by the new standard. The increase in the CAFE standard raises average fuel efficiency by less than 2 MPG because many firms are not constrained; some firms pay a greater fine than they did before, and other firms already exceed the new standard. The decrease in power and weight arises from the fact that constrained firms adjust prices so that consumers purchase more fuel efficient vehicles, which tend to be less powerful and lighter.

6.2 MEDIUM RUN COSTS

The second row of Table 5 reports the results of simulating a 2 MPG increase using the medium run model, (MR). All firms choose prices and vehicle characteristics to maximize profits. Firms are classified into the same three categories as before.

As noted above, the medium run simulation model includes two important differences from the short run model. First, each vehicle's fuel efficiency is endogenous and depends on weight, power and technology. The elasticities of fuel efficiency to power and weight were estimated in Section 4 and are shown in Table 1.

The second difference of the medium run model is that marginal costs are now endogenous. Because firms do not change characteristics in the short run, marginal costs are not affected by the CAFE standard in the short run.[12] However, marginal costs play an important role in the medium run analysis. For example, if marginal costs increase significantly when the firm reduces weight, firms would be unlikely to reduce weight. We assume a CES cost function, where the elasticity of costs to power is estimated using proprietary engine cost data. The elasticities of costs to weight and engine technology are estimated using data on the costs and efficacy of engine and weight reduction technologies from NHTSA (2008).[13] It is important to note that in the medium run analysis, only a limited set of engine technologies can be adopted. Therefore, the elasticity of costs to engine technology is greater in the medium run than in the long run (the short run elasticity is infinite).

The second row of Table 5 reports summary statistics from the medium run simulation. The differences across the short and medium run simulations underscore the importance of accounting for the endogeneity of vehicle characteristics. The overall changes in producer and consumer surplus are roughly half as large in the medium run as in the short run. This result is consistent with Jacobsen (2008), who finds that the long run cost is roughly one-third of the short run cost, so that the medium run costs lie between the two extremes. Section 4 suggests that short run changes in the sales mix are important for at most one or two years, while medium run

[12] We assume throughout that there are no economies of scale, so that marginal costs only depend on vehicle characteristics.

[13] The constant terms in equations (3) and (4) are estimates using the initial fuel efficiency and marginal cost of each model (i.e., before the increase in the standard). The final fuel efficiency and marginal cost are calculated using the deviations from the initial values of power, weight and technology.

changes in vehicle characteristics are important for roughly 5 years. Thus, previous studies significantly overstate the annual cost of the CAFE standard for horizons of roughly 2-5 years.

Many previous studies compare the cost of using the gasoline tax with the CAFE standard to achieve a given reduction in gasoline consumption. While a full comparison of the two policies is beyond the scope of this paper, it is still possible to assess them qualitatively. Although the medium run costs of the CAFE standard are much lower than the short run costs, the magnitudes do not overturn the conclusions of other studies that the gasoline tax is much less costly than the CAFE standard. Costs per gallon-saved may be half as great in the medium run as in the short run for CAFE, but total costs are still likely to be much greater than for the gasoline tax. For example, Jacobsen (2008) finds that the short run cost of the gasoline tax is roughly one-sixth the cost of the CAFE standard.

6.3 Robustness and Limitations

The Appendix Table reports a number of robustness checks for equation (2'). It is reassuring that the estimated demand for weight and power is insensitive to a few alternative specifications of the nesting structure (columns 1-3). The results do vary significantly in some of the other specifications, however, and the simulation results are also sensitive to these variations. We believe this sensitivity has not been emphasized enough in the previous literature, where standard practice is to report one or two specifications (note that the results are even more sensitive using the standard instrumental variable approach). In this context, the variation in the results across different, equally reasonable, specifications of the estimation model is likely to dominate sampling variation.

A few limitations of the analysis should be noted. The model used to perform the simulations uses the original structure of the CAFE standard, which was based on the harmonic mean of a firm's fuel efficiency. Future work will incorporate the new version of the standard, which is based on a vehicle's footprint (the product of length and width). 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 above considers the medium run effect of the CAFE standard, in which there is no entry (exit is modeled in the simulation, however). Explicitly allowing for the entry of vehicle models would require a dynamic framework and is a potential direction for future research.

7 Conclusion

The upcoming increase in the CAFE standard will significantly affect the new vehicles market. This paper analyzes the medium run effect of the standard, which we define as the response when engine technology is held constant but firms can change vehicle characteristics. This paper first shows that in response to the initial standard, firms significantly reduced the power and weight of models sold in the late 1970s and early 1980s in order to increase fuel efficiency, but technological progress caused power to recover in the long run. Average power in 1990 was similar to the level in 1978, during which time fuel efficiency increased significantly.

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

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Table 1

Tradeoff Between Fuel Efficiency, Weight and Power for Cars		
	Dependent Variable: Log Fuel Efficiency	
	(1)	(2)
Log Horsepower	-0.06 (0.03)	-0.15 (0.03)
Log Weight	-0.33 (0.07)	-0.33 (0.09)
R^2	0.90	0.84
Number of Observations	1989	1987
Fixed Effects	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 dummies and column 2 includes engine platform dummies.

Table 2

Sample Coverage by Vehicle Class, 2008

Vehicle Class	(1) Number of Models	(2) Number of Models with Instruments	(3) Fraction Sales	(4) Fraction Sales with Instruments
Small Cars	26	10	0.16	0.08
Mid-Size Cars	27	19	0.23	0.21
Large, Luxury and Specialty Cars	48	28	0.11	0.08
Small SUVs	27	23	0.13	0.13
Large SUVs	37	25	0.13	0.10
Vans	11	8	0.08	0.06
Pickup Trucks	15	11	0.16	0.14
Total	191	124	1.00	0.79

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 the 2008 model-year. 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 the 2008 model-year. Fraction sales with instruments is the fraction of sales in total sales for the models with instruments.

Table 3

Summary Statistics and First Stage Results				
	(1)	(2)	(3)	(4)
	Vehicle Price (Thousand $)	Power-to-Weight (Horsepower/Pound)	Weight (Tons)	Log Within-Class Share
	Panel A: Summary Statistics			
Mean	33.200	0.058	1.961	-3.934
Std Dev	(17.253)	(0.013)	(0.428)	(1.435)
	Panel B: First Stage Results			
Vehicle Price	0.048	-0.017	-0.004	-0.006
	(0.069)	(0.006)	(0.018)	(0.010)
Power	0.146	0.017	0.014	-0.005
	(0.011)	(0.002)	(0.004)	(0.001)
Weight	0.972	-1.035	7.001	1.208
	(2.608)	(0.331)	(1.050)	(0.509)
Fuel Efficiency	-0.399	0.109	-0.155	0.111
	(0.284)	(0.026)	(0.082)	(0.064)
Log Within-Class Share	-2.050	-0.337	0.527	0.092
	(0.438)	(0.041)	(0.140)	(0.066)
R^2	0.77	0.60	0.58	0.42
N	1344	1344	1344	1344

Notes: Panel A reports the mean and standard deviation of vehicle price (thousands of dollars), power-to-weight (horsepower per pound), weight (tons) and the log of the within-class market share. Instruments for vehicle price, power-to-weight, weight, and within-class market share are constructed from the matched engine model-vehicle model data set. The instruments are the mean of within-class deviations of vehicles belonging to other classes that have the same engine. The sample includes all models for which the instruments can be calculated, and spans 2000-2007. Panel B reports coefficient estimates with standard errors in parentheses, clustered by model. All regressions include firm-year interactions. Coefficients in column 2 are multiplied by 100 and the coefficients

Table 4

The Demand for Power and Weight

	Dependent Variable: Log Market Share		
	(1)	(2)	(3)
Vehicle Price	-0.003 (0.001)	-0.036 (0.008)	-0.053 (0.025)
Power-to-Weight	2.912 (1.546)	16.983 (5.137)	14.397 (10.432)
Weight	0.430 (0.039)	1.024 (0.164)	1.030 (0.480)
Log Within-Class Share	0.933 (0.012)	0.705 (0.046)	0.458 (0.344)
R^2	0.95	0.91	0.87
N	1344	1344	1344
Estimation Model	OLS	IV, BLP 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 are the price of the vehicle, in thousands of dollars; power-to-weight, in horsepower divided by weight, in pounds; weight, in tons; the log of the within class share of sales; and a set of firm and year dummies. Column 1 is estimated by Ordinary Least Squares and columns 2-4 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.

Table 5

Effects of a 2 MPG Increase in the CAFE Standard								
	Change in Cons Surplus (Billion $)	Change in Total Profits (Billion $)	Change in U.S. Firms' Profits (Billion $)	Change in Profits for Honda/Toyota (Billion $)	Percent Change in U.S. Market Share	Change in Fuel Efficiency (MPG)	Change in Horsepower	Change in Weight (Pounds)
Short Run	-8.59	-12.88	-21.19	4.35	-4.12	1.44	-12.25	-185.98
Medium Run	-5.56	-4.38	-11.84	2.04	-2.67	1.42	-20.65	-403.32

Notes: The table reports the effect of a 2 MPG increase in the CAFE standard on consumer surplus total profits, profits of U.S. firms, profits of Honda and Toyota (all in billions of 2007 dollars), the percent change in market share of U.S. firms, and the change in fuel efficiency (MPG), the change in horsepower and the change in weight (pounds). The two rows report the results of different simulations. In the first row, weight, power and fuel efficiency of each vehicle model are held constant, while in the second row these characteristics are chosen by the firm. See text for details on the simulations.

Appendix Table

Alternative Specifications

	Dependent Variable: Log Market Share						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Vehicle Price	-0.037 (0.018)	-0.025 (0.008)	-0.099 (0.173)	-0.010 (0.006)	-0.078 (0.069)	-0.050 (0.039)	-0.043 (0.032)
Power-to-Weight	16.317 (9.434)	18.078 (9.183)	10.818 (54.531)	4.919 (4.707)	23.133 (30.165)	14.927 (17.366)	
Power							0.003 (0.004)
Weight	1.343 (0.287)	0.809 (0.221)	2.867 (3.830)	0.674 (0.136)	2.390 (1.568)	1.347 (0.718)	0.916 (0.241)
Log Within-Class Share	0.844 (0.221)	0.988 (0.105)	0.244 (1.342)	0.945 (0.042)	0.133 (0.781)	0.446 (0.476)	0.548 (0.349)
R^2	0.92	0.95	0.76	0.98	0.56	0.79	0.86
N	1344	671	673	1344	1344	1344	1344
Specification	Combine SUVs	Cars Only	Trucks Only	Don't Demean Instr	Year x Class	Year and Firm	Separate Power and Weight

Notes: The table reports the specifications indicated in the bottom row. Column 1 combines the two SUV classes listed in Table 2. Columns 2 and 3 restrict the sample to include only cars and light trucks. Column 4 uses the levels of the characteristics as instruments, rather than the demeaned values. Column 5 adds year by vehicle class interactions. Column 6 includes sets of year and firm fixed effects instead of year-firm interactions. Column 7 includes power in place of the power-to-weight ratio.

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

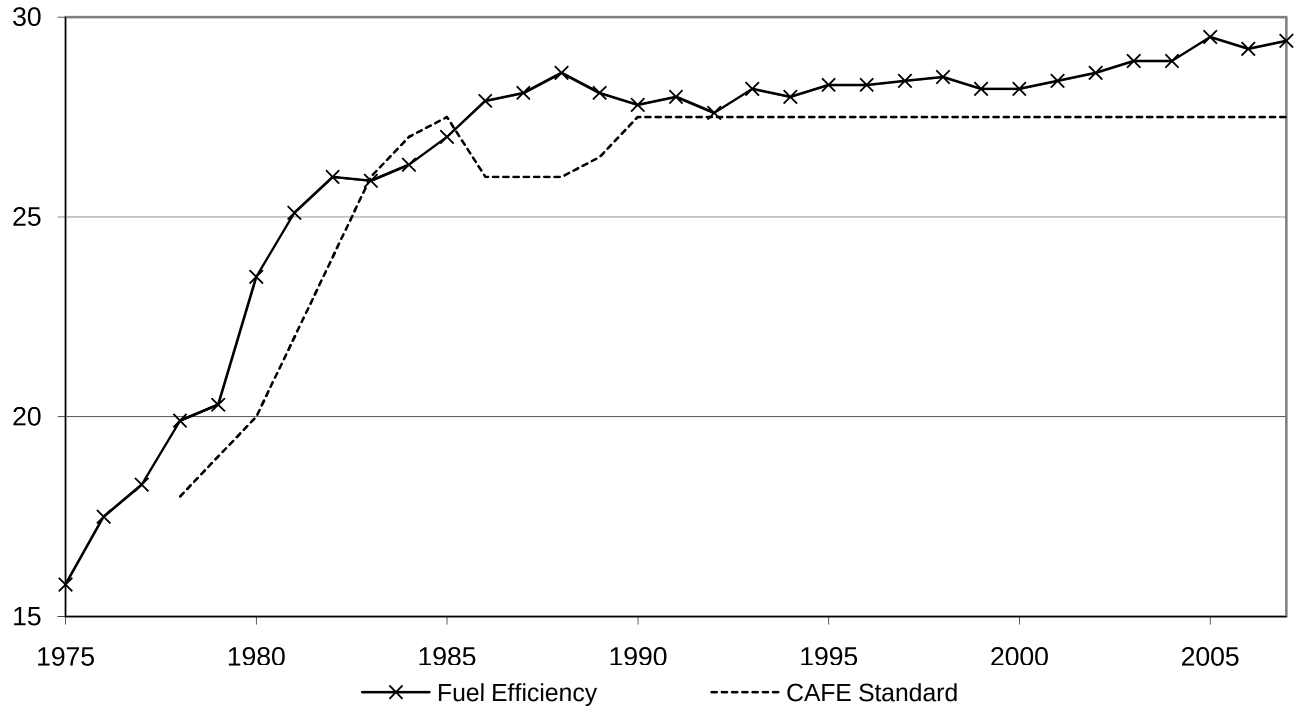

Figure 1b: Power and Weight of Cars, 1975-2007

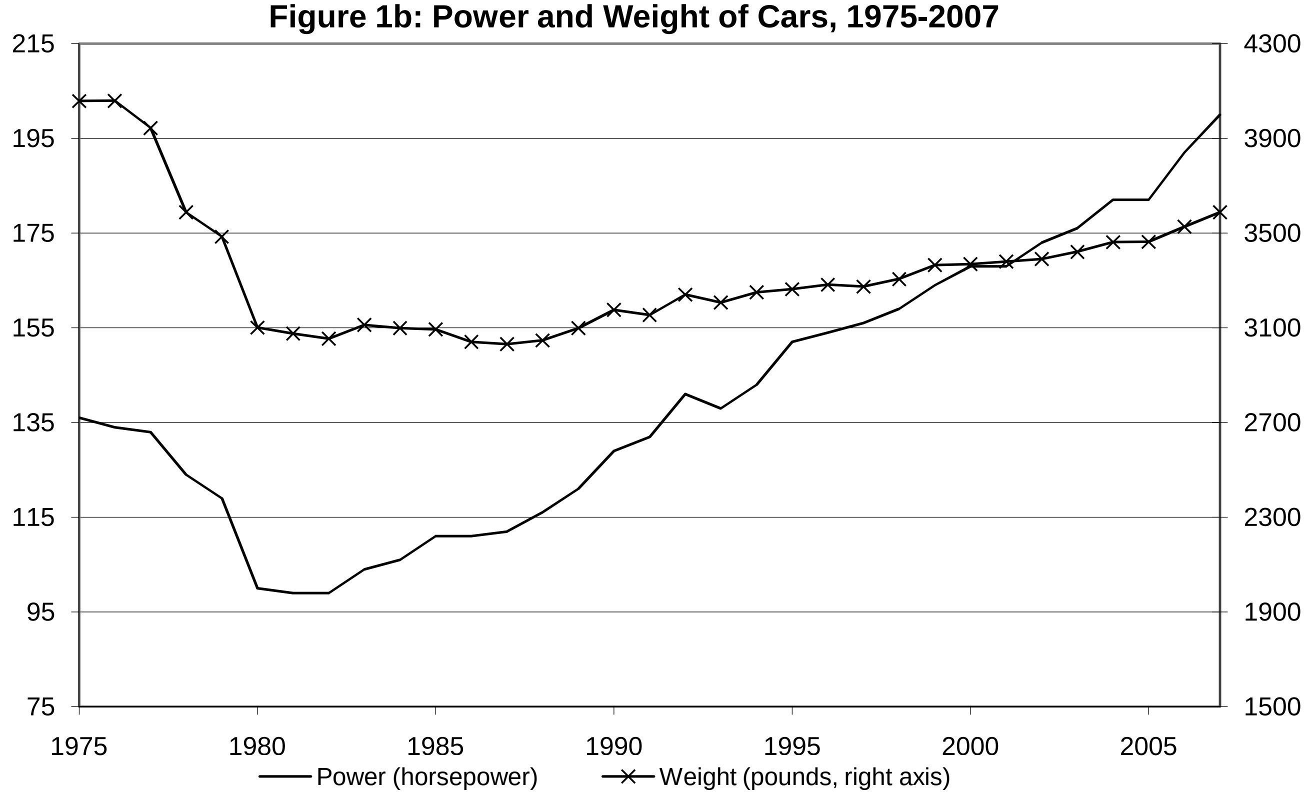

Figure 2a: Fuel Efficiency, Weight and Displacement for Cars of U.S. Manufacturers, 1975-2007

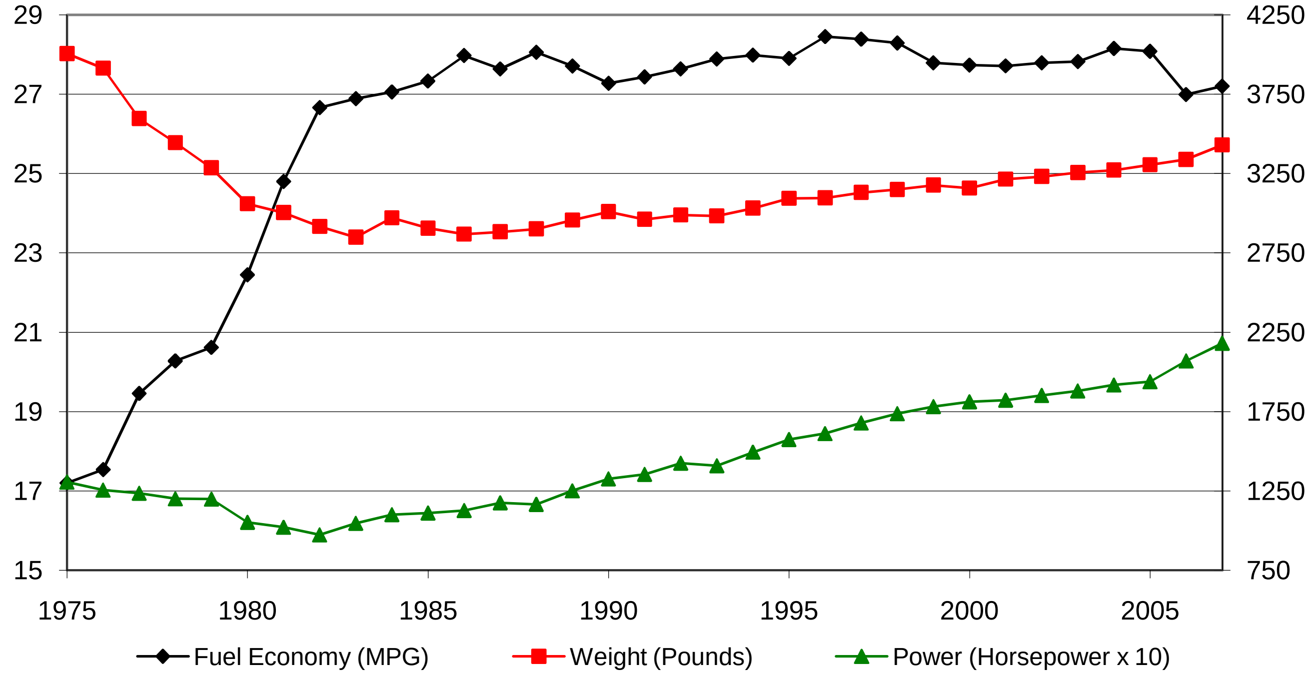

Figure 2b: Percent Change in Fuel Efficiency, Weight and Power, 1975-2007

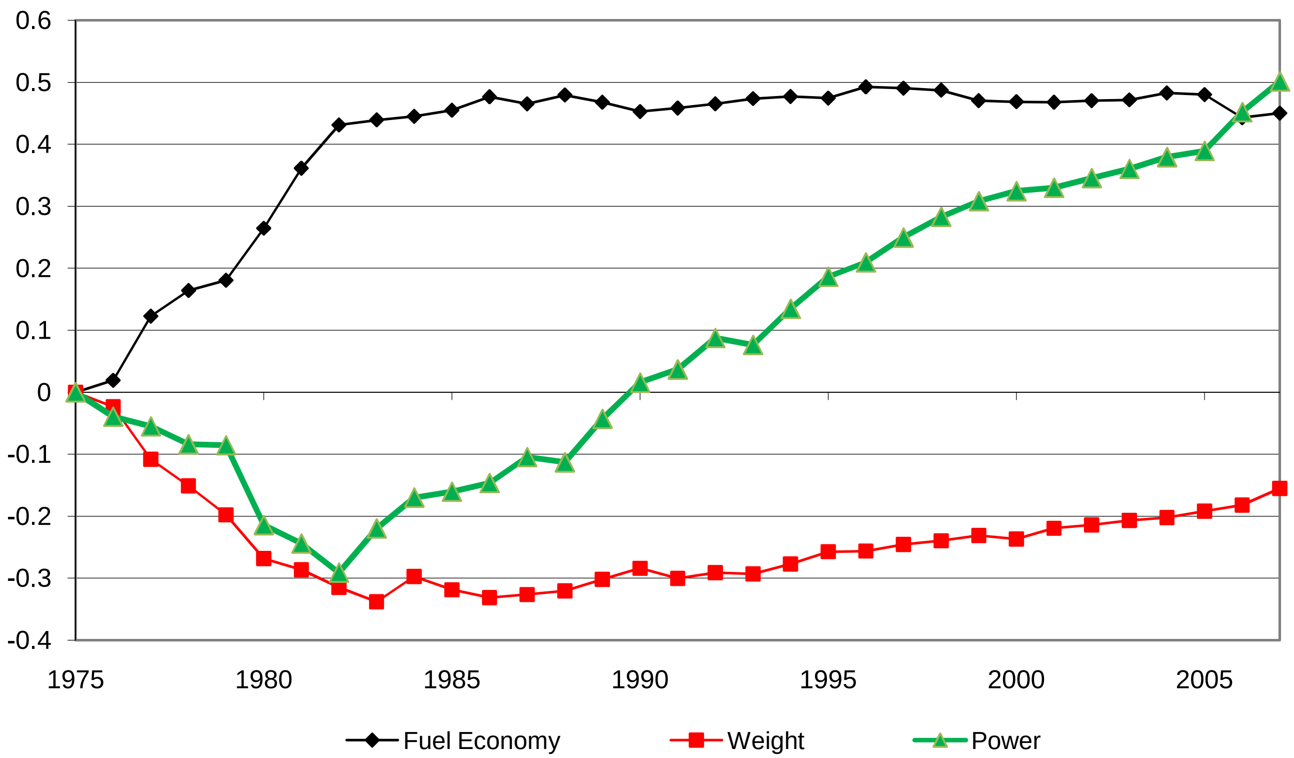

Figure 3: The Effect of Changes in Sales and Fuel Efficiency, Balanced Panel of U.S. Cars, 1975-1984

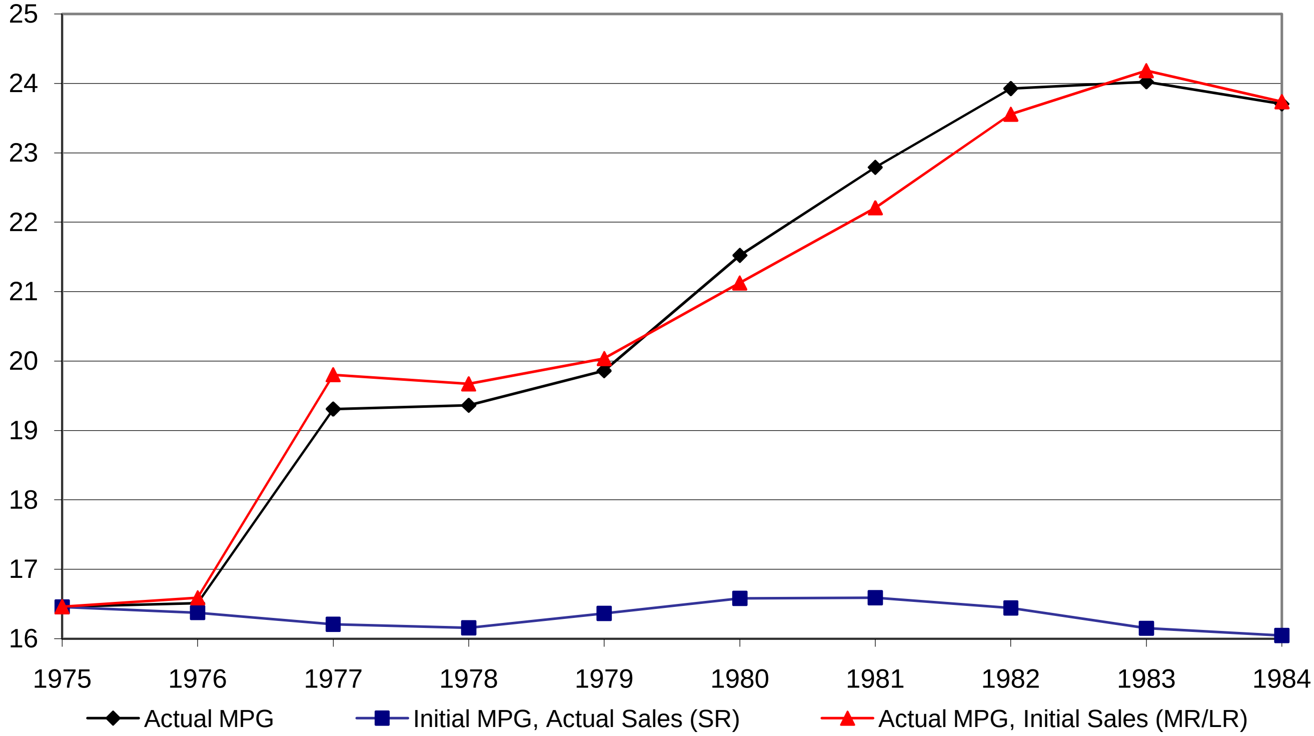

Figure 4: Effect of Power and Weight on Fuel Efficiency for U.S. Manufacturers, 1975-2007

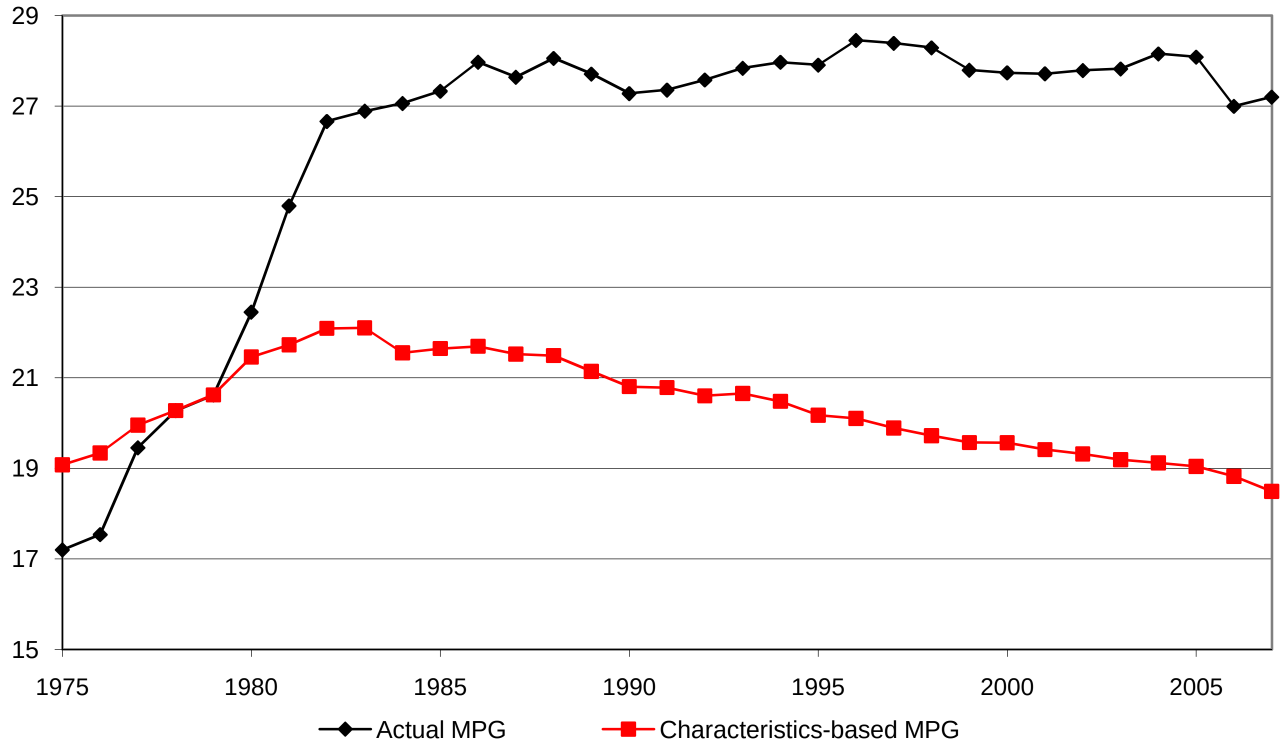

Figure 5: Change in Willingness-to-Pay Due to Changing Vehicle Characteristics for U.S. Firms, 1975-2007