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

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Abstract

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

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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 to

consumers and producers of using the CAFE standard to reduce gasoline consumption. These

studies simulate the effect of an increase in the standard on market equilibrium and can be

classified into two categories. Some, including Goldberg (1998), have used a short run model,

pertaining to one or two years after a change in the standard, in which vehicle characteristics and

technology are held constant. Firms respond to an increase in the CAFE standard by adjusting

vehicle prices, i.e., by changing the "sales mix." Other studies, such as Austin and Dinan (2005),

use a long run model, which pertains to 10 years or more after a change in the standard, to

estimate costs. In this model, firms choose vehicle prices and power train (engine and

transmission) technology.

Yet casual observation of the new vehicles market suggests that the preceding analysis is

overly simplified. Firms typically select vehicle prices every year and make major changes to

power train technology every ten years. But every four or five years, firms can redesign vehicles

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

The CAFE literature has concluded that the regulation is far more costly than using the gasoline tax to reduce gasoline consumption. However, because the previous analysis does not incorporate the medium run, total discounted costs may be significantly overstated. To the extent that reductions in weight and power or modifications to the power train are less costly than adjusting the sales mix, actual costs a few years after a change in the standard could be much lower than the short run analysis suggests. Medium run changes in characteristics may also

reduce the need to equip vehicle models with expensive advanced engine technologies in the long run, implying that the long run estimates may also be too high. Finally, the short run/long run distinction may overstate the length of time before significant improvements in fuel economy can be realized. But it is an empirical question whether the medium run is quantitatively important.

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

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

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[1] A number of studies in the 1980s analyzed the changes in weight, power and fuel efficiency after CAFE was adopted. Similarly to this study, Greene (1987 and 1991) concludes that short run changes in the sales mix explain a small share of the increase in fuel efficiency and that technology explains about half of the increase in fuel efficiency. Greene and Liu (1988) calculate the change in consumer surplus after CAFE was adopted using changes in these characteristics and willingness-to-pay estimates from other studies However, the earlier studies do not perform the analysis at the engine level, as this paper does, and they pertain to a shorter time period.

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valid only if characteristics observed by the econometrician are uncorrelated with unobserved characteristics, which seems unlikely to be the case; e.g., a larger vehicle may have worse handling.

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

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

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[2] In Sweeting (2007), unobserved station quality is exogenous, but is potentially correlated with observed characteristics. Sweeting uses the timing assumption to construct a valid set of instruments using lagged variables.

Furthermore, the long run analysis does not reveal the substantial improvements in fuel efficiency that can be attained only a few years after a new standard is adopted. On the other hand, the cost of reducing gasoline consumption in the medium run is probably greater using the CAFE standard than the cost of using the gasoline tax.

2 DATA

This paper uses a detailed data set of vehicle and engine characteristics and vehicle sales from 1975-2008. Klier and Linn (2008) describe the vehicle characteristics and sales data in more detail. Vehicle sales are from the weekly publication Ward's Automotive Reports for the 1970s and from Ward's AutoInfoBank in subsequent years. Sales are matched to vehicle characteristics by vehicle model from 1975-2008.[3] The characteristics data are available in print in the annual Ward's Automotive Yearbooks (1975-2008), and include horsepower, curb weight, length, fuel efficiency and retail price. Note that the data do not include fuel efficiency from 1975-1977, as fuel efficiency was not reported prior to the CAFE program. We impute fuel efficiency from the other vehicle characteristics during these years, using the estimated relationship among characteristics for 1978-1979.

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

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

(2007), the share of light trucks in the new vehicles market was between 20 and 30 percent between the years 1975 and 1988.

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

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

3 FUEL EFFICIENCY REGULATION AND ENGINE TECHNOLOGY

3.1 THE CAFE STANDARD

Following the 1973 oil crisis, Congress passed the Energy Policy and Conservation Act in 1975 in order to reduce oil imports.[4] The Act established the CAFE program and required automobile manufacturers to increase the average fuel efficiency of passenger and non-passenger vehicles sold in the United States. There are separate standards for cars and light trucks, which have varied slightly over time; for model-year 2007, the standards are 27.5 miles per gallon (MPG) for cars and 22.2 MPG for light trucks. Firms may also earn credits for over-compliance that can be used in future years. The standards are administered by the U.S. Department of Transportation (DOT) on the basis of the U.S. Environmental Protection Agency's test procedure for measuring fuel efficiency.

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

3.2 CAFE AND MARKET OUTLOOK

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

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

Engine technologies improved over time, which allowed firms to improve a vehicle's performance while continuing to meet the CAFE standard.

Many industry analysts believe that because many of the "easy" improvements to engine technology were made in response to the initial CAFE standard, the future increase in the standard may be much more costly to producers and consumers. While new power train systems, such as those relying on hybrid electric and diesel technologies, have begun to penetrate the U.S. market, the vast majority of vehicles are powered by conventional gasoline-powered spark-ignition engines. While essentially every vehicle manufacturer is advertising its alternative power train research, as of 2007, sales of hybrid vehicles represent about 2 percent of total sales of cars and light trucks.[5] Thus, once again, the performance characteristics of the existing gasoline engine technology, as well as the related transmission technologies, are the focus of attention.

3.3   THE MEDIUM RUN

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

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

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

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

4   RESPONSE TO THE INITIAL CAFE STANDARD

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

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

The increase in fuel efficiency in Figure 1 could be due to short run changes in the sales mix; medium run changes in power, weight or technology; or the long run adoption of power train technology. This section decomposes the total increase in fuel efficiency into these three effects. The analysis in this section focuses on cars sold by U.S. automobile manufacturers (Chrysler, Ford and GM) for two reasons. First, as Jacobsen (2008) notes, there have been three categories of firms: firms that consistently exceed the standard by a large amount (e.g., Honda and Toyota); firms that are constrained by the standard and typically meet it (e.g., Ford); and firms that consistently pay a fine for not meeting the standard. U.S. firms account for the vast majority of sales from the constrained category, so the response of U.S. firms to the CAFE standard is of particular interest. The second reason for focusing on U.S. cars is that the light truck data are incomplete, and do not allow for a complete analysis for trucks in the 1970s and 1980s.

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

At the same time as fuel efficiency was increasing, weight and power were decreasing. Both power and weight decreased by about 25 percent between 1975 and 1982, after which they

increased steadily. In summary, the increase in fuel efficiency following the imposition of the

CAFE standard coincided with a large decrease in power and weight. Subsequently, weight and

power increased while fuel efficiency did not change.

The remainder of this section assesses the magnitudes of the short, medium and long run

responses to CAFE. We first separate the short run from the medium and long run. We abstract

from entry and exit decisions and analyze a balanced panel of vehicle models that have positive

sales each year from 1975-1984, which Figure 2 shows to be the main period in which fuel

efficiency increased.[6] The first data series in Figure 3 is the sales-weighted fuel efficiency of the

vehicle models in the sample, which follows a very similar pattern to Figure 2. Two

counterfactual series are constructed for this figure, which separate the short run changes in

average fuel efficiency from the medium and long run. The first series is the sales-weighted

average fuel efficiency, which is calculated using the actual sales of the vehicle models in each

year and the fuel efficiency in 1975; this series illustrates the effect of changes in the sales mix,

as an increase in the sales of vehicle models that initially have high fuel efficiency would cause

the sales-weighted average fuel efficiency to increase. The second series plots average fuel

efficiency using the sales weights in 1975 and the actual fuel efficiency of the vehicle model

each year, which includes medium and long run changes in fuel efficiency.[7] 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.

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

[7] Note that the change in sales-weighted average fuel efficiency equals the sum of the effect of the change in sales mix, plus the effect of within-model changes in MPG, plus a cross-term:

$$\Delta \overline{M}_t = \sum_j \Delta s_{jt} M_{j0} + \sum_j s_{j0} \Delta M_{jt} + \sum_j \Delta s_{jt} \Delta M_{jt}$$. Figure 2 reports changes in MPG due to changes in the

sales weights and within-model changes in fuel efficiency; i.e., the final term is omitted. In practice, the omitted term explains less than 10 percent of the overall change in all years, and is not shown for clarity.

Thus, within the first 10 years of the introduction of the CAFE standard, firms largely complied by increasing fuel efficiency rather than adjusting the sales mix.

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

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

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

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 2 reports the results of estimating equation (1). The two columns include engine program and engine platform fixed effects (recall that multiple engine programs belong to the same platform). The reported coefficients are the within-program and -platform effects of power and weight on fuel efficiency. The two specifications should be considered to be lower and upper bounds of the medium run effect of weight and power on fuel efficiency. The within-program elasticity of fuel efficiency with respect to power is -0.07 and for weight is -0.33; the estimate for power is larger in column 2 with platform fixed effects. On the other hand, the effect of weight

on fuel efficiency is the same, which is as expected because weight varies at the vehicle level and not the engine level.

Overall, Table 2 suggests that firms can increase fuel efficiency by decreasing power and weight. Assuming the elasticities have not changed over time, we can use the estimated parameters in equation (1) to obtain a lower bound of the medium run response to CAFE. In particular, we use the actual weight and power each year from 1975-2007 for the sample in Figure 2, combined with the estimates in column 1 of Table 2, to predict the fuel efficiency of each vehicle. The predicted series captures medium run changes in weight and power, but does not include medium run technology adoption. The difference between the actual and predicted series can be interpreted as the effect on fuel efficiency of medium and long run technology adoption. Figure 4 shows the actual and predicted fuel efficiency from 1975-2007. The figure demonstrates that decreases in power and weight explain about one-third of the increase in fuel efficiency in the late 1970s and early 1980s.[8] Given that this is probably a lower bound, we conclude that the medium run response to the CAFE standard has been historically important.

5 ESTIMATING WILLINGNESS-TO-PAY FOR ENGINE POWER AND WEIGHT

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

5.1 THE NEW VEHICLES MARKET

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

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

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characteristics for the vehicles they sell. Consumer demand for each vehicle model depends on its price and characteristics, and each period there is a market clearing vector of prices, quantities and characteristics.

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

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

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

The next term in equation (2), 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 vehicle'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 set of vehicles J_f:

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

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

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

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

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

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

$$\ln M_{jt} = \delta_0 + \delta_1 \ln H_{jt} + \delta_2 \ln W_{jt} + T_{jt} \qquad \text{(b)}$$

$$\ln c_{jt} = \gamma_0 + \gamma_1 \ln H_{jt} + \gamma_2 \ln W_{jt} + \gamma_3 \ln T_{jt} \qquad \text{(c)}$$

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.[9] The marginal

cost of the vehicle model is given by equation (c), and depends on the power of the engine, the

weight of the vehicle and the engine technology. Note that improving engine technology raises

fuel efficiency and therefore demand for the vehicle, but also raises costs; this tradeoff is

governed by the coefficient on dollars-per-mile in equation (2) and the cost elasticity in (c).

Analogous tradeoffs exist for increasing weight and power. In equilibrium, firms choose the

profit-maximizing vectors of prices and vehicle characteristics and consumers choose vehicles

based on the prices and characteristics.

The equilibrium depends on supply and demand parameters, but also on the CAFE standard.

Similarly to past research, we are interested in the effect of the CAFE standard on the market

equilibrium. To answer this question, it is necessary to estimate the parameters in equation (2).

Estimating the demand for fuel efficiency, 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

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[9] Equation (b) is similar to equation (1) above, but the subscripts are different. Equation (1) is estimated using observations at the engine-vehicle model level. Sales data are only available by vehicle model and year, however, and the analysis in this section is aggregated to that level.

this approach to estimate the coefficients in equation (2) for the variables that do not vary within

the model-year, 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.

Estimating equation (2') is far more challenging than in a short run setting. Firms choose the

characteristics of each vehicle, taking as given the characteristics of the vehicles sold by other

firms in the market. From the first order conditions for (MR), the observed characteristics are

correlated with the unobserved characteristics of the same vehicle model, and with both observed

and unobserved characteristics of other vehicles. For example, if Honda increases the power of

one of its Acura car models, Toyota may increase the power of the Lexus car models that are

substitutes for the Acura.

Because of this correlation, estimating equation (2') by Ordinary Least Squares (OLS) would

yield biased estimates of all coefficients. The endogeneity of vehicle characteristics implies that

three standard approaches would also yield biased estimates. First, including vehicle fixed effects

would only address the problem if one assumes that unobserved characteristics do not change

over time (i.e., $\xi_{jt} = \xi_j$). In that case, the parameters would be identified by within-model

changes in prices, power and weight. This assumption is not appropriate because there are many

unobserved characteristics, such as interior cabin space, that firms can change as readily as

power and weight.

The second approach would be to follow many previous studies of automobile demand, such

as BLP, and use moments of vehicle characteristics of other vehicles in the same class or other

vehicles sold by the same firm to instrument for the price and within-class market share. The

instruments are valid if characteristics are exogenous, in which case the instruments would be

correlated with vehicle prices (via first order conditions in model SR), but would not be correlated with the unobserved characteristics. Such an argument cannot be made in the medium run analysis, however, in which characteristics are endogenous. A similar argument can be made for the third approach, performing a hedonic analysis (e.g., McManus, 2005).

5.2   ESTIMATION STRATEGY

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

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

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

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

The power of the two vehicles is correlated because they have the same engine. The class

intercepts, η_c, are arbitrary, potentially nonlinear, functions of the characteristics of other

vehicles in the same class, as well as non-engine characteristics of the same vehicle. The

intercepts allow for class-specific demand and supply shocks, so that the power of the two

vehicles will differ because of variation across classes in consumer preferences and the

characteristics of the other vehicles in the respective classes.

The instrumental variables (IV) strategy is based on equation (3), in which we instrument for

a vehicle's price, power-to-weight, weight and within-class market share. The instruments are

the means of eight engine characteristics of vehicle models that are located in other classes, but

which have the same engine platform.[10] The IV strategy yields unbiased estimates of the demand

for power and weight if the error term in equation (3) is uncorrelated across classes for vehicles

that have the same engine.[11] Note that this assumption is considerably weaker than the standard

assumption that observed and unobserved characteristics are uncorrelated.[12]

Although this approach relaxes the assumption that vehicle characteristics are exogenous,

there are several potential sources of bias. First, there may be unobserved brand-specific fixed

effects or trends, which would cause η_c to be correlated across classes. To address this concern,

the specification includes brand-year interactions; for example, the approach would be robust if

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[10] The instruments are listed in Appendix Table 1 and include fuel efficiency, power, weight, power-to-weight, torque, the number of valves, the number of cylinders and displacement. The instruments are calculated as the mean deviation from the class mean to account for the class intercepts in equation (3). The results are similar if means rather than mean deviations are used to construct the instruments. We prefer to construct the instruments using engine platforms rather than engine programs because the sample size is much larger and the instruments for a particular vehicle are constructed from a wider range of other vehicles, which probably reduces bias. Note that the results are sensitive to this distinction, however, as the demand for power is small and not statistically significant using program-based instruments.
[11] We assume that demand is uncorrelated across vehicle classes. Strictly speaking, this is not the case in the nested logit framework, but cross-class demand elasticities are second order in magnitude.
[12] Estimating equation (2') is preferable to equation (2) because the same set of instruments is available for both equations, but (2') has one less endogenous variable. An additional advantage is that power, weight and fuel efficiency are highly correlated with one another, making it difficult to obtain robust estimates of the coefficients on dollars-per-mile, power and weight if all variables are included in the IV estimation.

all Honda models share common unobserved characteristics. Second, the estimates would be

biased if there were unobserved engine characteristics. However, we believe that the included

variables in equation (2') capture the main features that consumers use to differentiate engines,

as the results are robust to adding other engine characteristics, such as the number of cylinders or

the engine's torque. Finally, the decision to use a particular engine in a vehicle model may be

endogenous. The identifying assumption is that the correlation of characteristics across vehicle

models is driven by the common engine technology, but this may not be valid if unobserved

vehicle characteristics are also correlated across models with the same engine. We can partially

address this issue by using lagged engine characteristics as instruments, which takes advantage

of the fact that engines are redesigned at longer time scales than the rest of the vehicle.

Consequently, the correlation between the instruments and endogenous variables is more likely

to be driven by a common engine technology, rather than common unobserved characteristics.

The results are not sensitive to using lagged values to construct the instruments (see section 6.3

and Table 7 for robustness checks).

5.3   VARIATION IN ENGINES AND FIRST STAGE RESULTS

Before reporting the results of estimating equation (2'), we summarize the engine variation

across vehicle models and discuss the first stage estimates for equation (2'). Each row in Table 3

includes a different vehicle class. Column 1 shows the number of vehicle models in 2008 and

column 2 shows the number of vehicle models in the sample for 2008. The sample only includes

vehicles that have an engine found in a vehicle from a different vehicle class, i.e., for which the

instruments can be constructed. Only about two-thirds of the vehicles are in the sample, but

columns 3 and 4 show that the sample includes 87 percent of total sales. Furthermore, except for

small cars, the sample includes nearly all of the sales for each class. It is important to note that it would be possible to increase the sample size by defining narrower vehicle classes. There is a tradeoff between sample size and bias, however, because with narrower classes it is more likely that demand shocks are correlated across classes, invalidating the IV approach.

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

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

5.4   THE DEMAND FOR POWER AND WEIGHT

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

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

characteristics is ambiguous because they may be positively or negatively correlated with unobserved characteristics.

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

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

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

If the demand for weight and power is sufficiently large relative to the demand for fuel efficiency, the decrease in weight and power in the late 1970s and 1980s for U.S. cars would have reduced willingness-to-pay for these vehicles. Figure 5 plots the change in willingness-to-

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

6   SIMULATION RESULTS AND INTERPRETATION

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

6.1   SHORT RUN EFFECTS OF AN INCREASE IN THE CAFE STANDARD

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

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[13] Greene and Liu (1988) perform a similar analysis and reach the same conclusion using estimates of willingness-to-pay for characteristics from other studies performed in the 1970s and 1980s.

consistently exceeded the standard by a wide margin and are unconstrained; Chrysler, Ford and GM and a few other firms have generally been close to the standard and are constrained; and all other firms have been well below the standard. The constrained firms solve problem (SR), while the other firms do not have a constraint; unconstrained firms that do not satisfy the constraint pay a fine. In performing the simulations, we assume that firms do not change categories as a result of the increase in the standard.

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

6.2 MEDIUM RUN EFFECTS (PRELIMINARY)

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

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

The second difference of the medium run model is that marginal costs are now endogenous. Because firms do not change characteristics in the short run, marginal costs are not affected by the CAFE standard in the short run.[14] However, marginal costs play an important role in the medium run analysis. For example, if marginal costs increase significantly when firms reduce weight, firms would be unlikely to do so. We assume a CES cost function, where the elasticity of costs to power is estimated using proprietary engine cost data. Similarly to Austin and Dinan (2005), the elasticities of costs to weight and engine technology are estimated using data on the costs and efficacy of engine and weight reduction technologies from NHTSA (2008).[15] It is important to note that in the medium run analysis, only a limited set of engine technologies can be adopted. Therefore, the elasticity of costs to engine technology is greater in the medium run than in the long run (the short run elasticity is infinite).

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

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

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

simulations underscore the importance of accounting for the endogeneity of vehicle characteristics. The overall changes in producer and consumer surplus are roughly half as large in the medium run as in the short run. This result is consistent with Jacobsen (2008), who finds that the long run cost is roughly one-third of the short run cost, so that the medium run costs lie between the two extremes. Section 4 suggests that short run changes in the sales mix are important for at most one or two years, while medium run changes in vehicle characteristics are important for roughly 5 years. Thus, previous studies significantly overstate the annual cost of the CAFE standard for horizons of about 2-5 years.

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

6.3 ROBUSTNESS AND LIMITATIONS

Table 7 reports a number of robustness checks for equation (2'). Columns 1-4 assess the importance of including brand-year interactions, add vehicle class-year interactions and address potential serial correlation. The coefficient on power-to-weight is considerably smaller if class-year interactions are added to equation (2'). Columns 5 and 6 address functional form assumptions by including power and weight separately and adding other engine characteristics on the right-hand-side; the results are similar in both cases. Column 7 shows that the estimated coefficient on power-to-weight is smaller if additional instruments are included. The estimate is

not affected using lagged instruments (columns 8 and 9), which addresses the potentially endogenous choice of which engines are paired with which vehicles (see Section 5.3). Overall, the results are somewhat sensitive to the alternative specifications, although the estimate on power-to-weight is positive in all specifications and is statistically significant in most. We use the specification in Table 5 for the simulations because of the relatively large estimate on power-to-weight. The fact that the large estimate is used implies that the decrease in costs between the short and medium run may be at least as large as reported in Table 6.

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

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

Finally, the policy scenario discussed above considers the medium run effect of the CAFE standard, in which there is no entry (exit is modeled in the simulation, however). Explicitly allowing for the entry of vehicle models is a potential direction for future research.

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 vehicles sold in the late 1970s and early 1980s in order to increase fuel efficiency, but technological progress caused power to recover in the long run.

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

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, Penelope 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 (2008). "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 National Highway Traffic Safety Administration, 2008. Preliminary Regulatory Impact Analysis for the Corporate Average Fuel Economy for MY 2011-2015 Passenger Cars and Light Trucks.

20 Ohnsman, Alan. 2008. "Honda bucks industry with TSX favoring fuel efficiency over power," Bloomberg. February 15

21 U.S. EPA, 2007. Light-Duty Automotive Technology and Fuel efficiency Trends: 1975 through 2007. EPA 420-R-07-008

22 Petrin, Amil (2002). "Quantifying the Benefits of New Products: The Case of the Minivan." *Journal of Political Economy*: vol. 110, 705-729.

23 Sweeting, Andrew (2007). "Dynamic Product Repositioning in Differentiated Product Markets: The Case of Format Switching in the Commercial Radio Industry." NBER Working Paper #13522.

24 Ward's Automotive Yearbook, 1980-2003, Ward's Communications.

25 Ward's AutoInfoBank, Ward's Automotive Group.

Table 1

Examples of Medium and Long Run Engine and Transmission Changes

	Medium Run			Long Run	
Technology	Cost ($)	Percent Increase in MPG	Technology	Cost ($)	Percent Increase in MPG
Low Friction Lubricants	3	0.5	Turbocharge/ Downsize	120	5-7.5
Variable Valve Timing	59-209	1-3	Continuously Variable Trans	139	3.5
5-speed Automatic Transmission	76-167	0.5-2.5	Automatic Manual Transmission	141	4.5-7.5
Cylinder Deactivation	203	4.5-6	PHEV	6750	28

Source: NHTSA (2008). All figures represent estimates for a mid-size car.

Table 2

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	1989
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 3

	(1)	(2)	(3)	(4)
Sample Coverage by Vehicle Class, 2008				
Vehicle Class	Number of Vehicle Models	Number of Vehicle Models with Instruments	Fraction Sales	Fraction Sales with Instruments
Small Cars	36	15	0.16	0.10
Mid-Size Cars	38	22	0.20	0.19
Large, Luxury and Specialty Cars	68	46	0.12	0.10
Small SUVs	56	40	0.18	0.16
Large SUVs	43	34	0.11	0.11
Vans	15	10	0.07	0.06
Pickup Trucks	21	18	0.16	0.16
Total	277	185	1.00	0.87

Notes: Vehicles are assigned to the vehicle classes, which are defined in the Wards database. The number of vehicle models is the number of unique models in each class in the 2008 model-year. The number of vehicle models with instruments is the number of models for which there is another model that belongs to a different class and has the same engine. Fraction sales is the share of sales of vehicle models in the class in total sales in the 2008 model-year. Fraction sales with instruments is the fraction of sales in total sales for the vehicle models with instruments.

Table 4

Summary Statistics

Variable Name	Mean	Standard Deviation
Log Market Share	-4.717	1.490
Vehicle Price	33.192	18.002
Power-to-Weight	0.059	0.014
Weight	1.911	0.421
Log Within-Class Market Share	-4.076	1.445

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

Table 5

Willingness-to-Pay for Power and Weight

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

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

Table 6

Effects of a 2 MPG Increase in the CAFE Standard

	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	-19.37	-17.46	-25.43	7.68	-8.82	1.33	-11.36	-184.46
Medium Run	-8.16	-8.18	-8.26	2.14	-3.46	1.42	-24.11	-421.19

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

Table 7

Alternative Specifications

Dependent Variable: Log Market Share

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Vehicle Price	-0.051 (0.017)	0.001 (0.005)	-0.050 (0.030)	-0.004 (0.012)	-0.058 (0.021)	-0.050 (0.017)	-0.028 (0.008)	-0.034 (0.023)	-0.081 (0.047)
Power-to-Weight	33.100 (11.369)	6.646 (2.622)	32.785 (19.452)	21.003 (10.898)		23.990 (9.190)	20.943 (6.785)	39.913 (22.044)	66.969 (36.952)
Power					0.010 (0.004)				
Weight	1.377 (0.299)	0.483 (0.103)	1.350 (0.536)	0.214 (0.238)	0.485 (0.248)	0.026 (0.541)	1.020 (0.129)	1.104 (0.307)	1.726 (1.888)
Log Within-Class Share	0.620 (0.125)	0.968 (0.029)	0.628 (0.223)	0.421 (0.119)	0.591 (0.137)	0.819 (0.076)	0.781 (0.060)	0.718 (0.204)	0.367 (0.366)
Lag Dep Var				0.565 (0.102)					
R^2	0.86	1.00	0.88	0.91	0.87	0.88	0.94	0.90	0.69
N	1804	1804	1804	1496	1804	1804	1804	1089	1151
Spec	Year and Brand Dummies	Add Class-Year Interactions	Cluster by Model	Add Lag Dep Var	Separate Power, Weight	Add Torque and Disp	Other Engine Instr	3-yr Lagged Instr	Lagged 3-yr Mean Instr

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

Appendix Table 1

First Stage Estimates

Dependent Variable:

	Vehicle Price (Thousand $)	Power-to-Weight (Horsepower/Pound)	Weight (Tons)	Log Within-Class Share
Fuel Efficiency	-0.168 (0.082)	-0.236 (0.104)	-0.415 (0.315)	-0.637 (1.339)
Power	-0.107 (0.034)	-0.088 (0.039)	-0.043 (0.058)	1.655 (0.338)
Weight	2.596 (6.197)	12.046 (5.515)	12.437 (13.955)	-1.288 (58.066)
Power-to-Weight	-0.041 (0.040)	-0.151 (0.066)	-0.014 (0.139)	1.533 (0.614)
Torque	0.054 (0.031)	-0.045 (0.021)	0.327 (0.065)	-0.025 (0.298)
Number of Valves	0.945 (0.126)	1.167 (0.154)	-1.024 (0.390)	-10.968 (1.455)
Number of Cylinders	0.840 (0.915)	-3.253 (1.081)	4.330 (3.501)	-17.415 (12.606)
Displacement	0.006 (0.002)	0.009 (0.003)	0.009 (0.005)	-0.061 (0.028)
R^2	0.66	0.38	0.56	0.39
N	1804	1804	1804	1804

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

Appendix Table 2

Alternative Specifications With BLP Instruments

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
				Dependent Variable: Log Market Share			
Vehicle Price	-0.070 (0.014)	-0.021 (0.009)	-0.026 (0.013)	0.004 (0.006)	-0.123 (0.018)	-0.026 (0.007)	-0.010 (0.005)
Power-to-Weight	29.738 (9.071)	-5.779 (5.990)	1.544 (8.482)	-5.705 (3.499)		-4.483 (4.400)	-1.552 (2.893)
Power					0.019 (0.003)		
Weight	1.710 (0.262)	1.159 (0.186)	0.895 (0.245)	0.123 (0.110)	0.681 (0.123)	0.582 (0.147)	0.805 (0.080)
Log Within-Class Share	0.430 (0.074)	0.356 (0.092)	0.420 (0.115)	0.181 (0.063)	0.346 (0.097)	0.419 (0.070)	0.675 (0.042)
Lag Dep Var				0.694 (0.061)			
R^2	0.76	0.81	0.83	0.89	0.59	0.83	0.95
N	1804	1804	1804	1496	1804	1804	1804
Specification	Year and Brand Dummies	Add Class Dummies	Cluster by Model	Add Lag Dep Var	Separate Power, Weight	Add Torque and Disp	Add Car/Truck Nest

Notes: The table reports the specifications indicated in the bottom row. All specifications are the same as the corresponding columns in Table 7, except that the BLP instruments from column 2 of Table 5 are used, rather than the engine-based instruments

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

Fuel Efficiency   ------- CAFE Standard
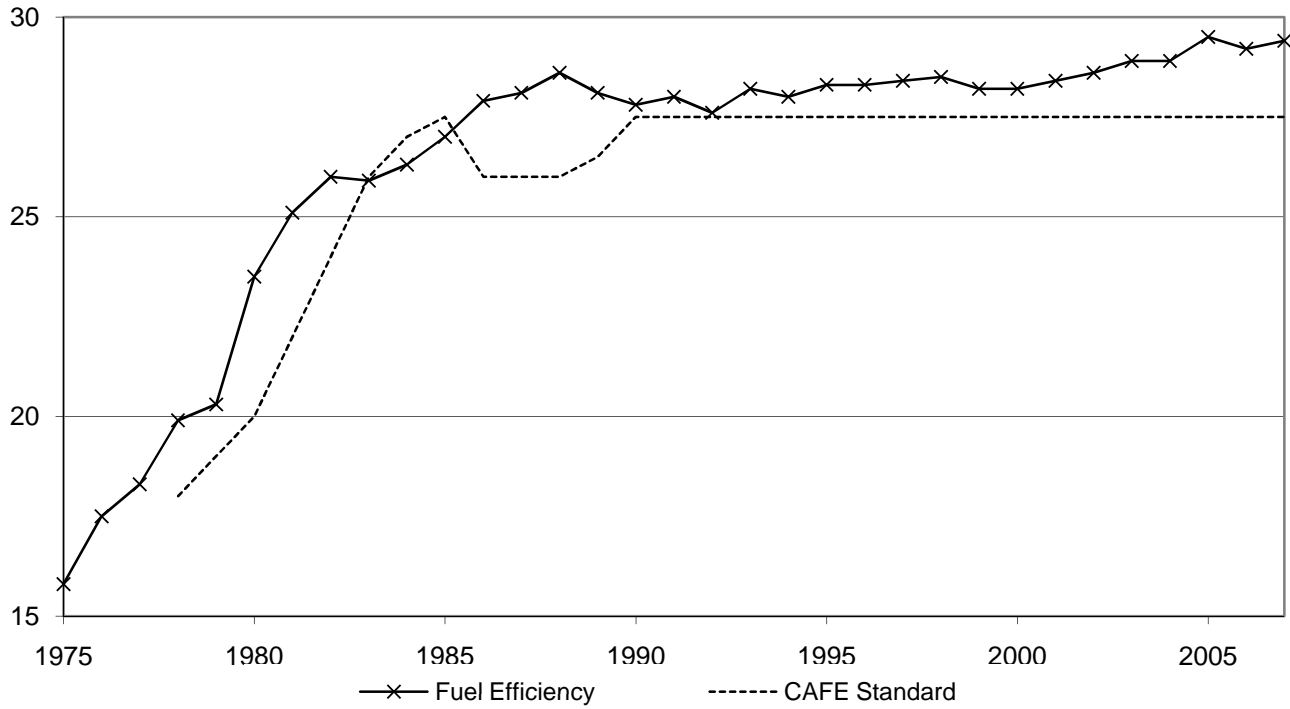
Figure 1b: Power and Weight of Cars, 1975-2007

Power (horsepower)   Weight (pounds, right axis)
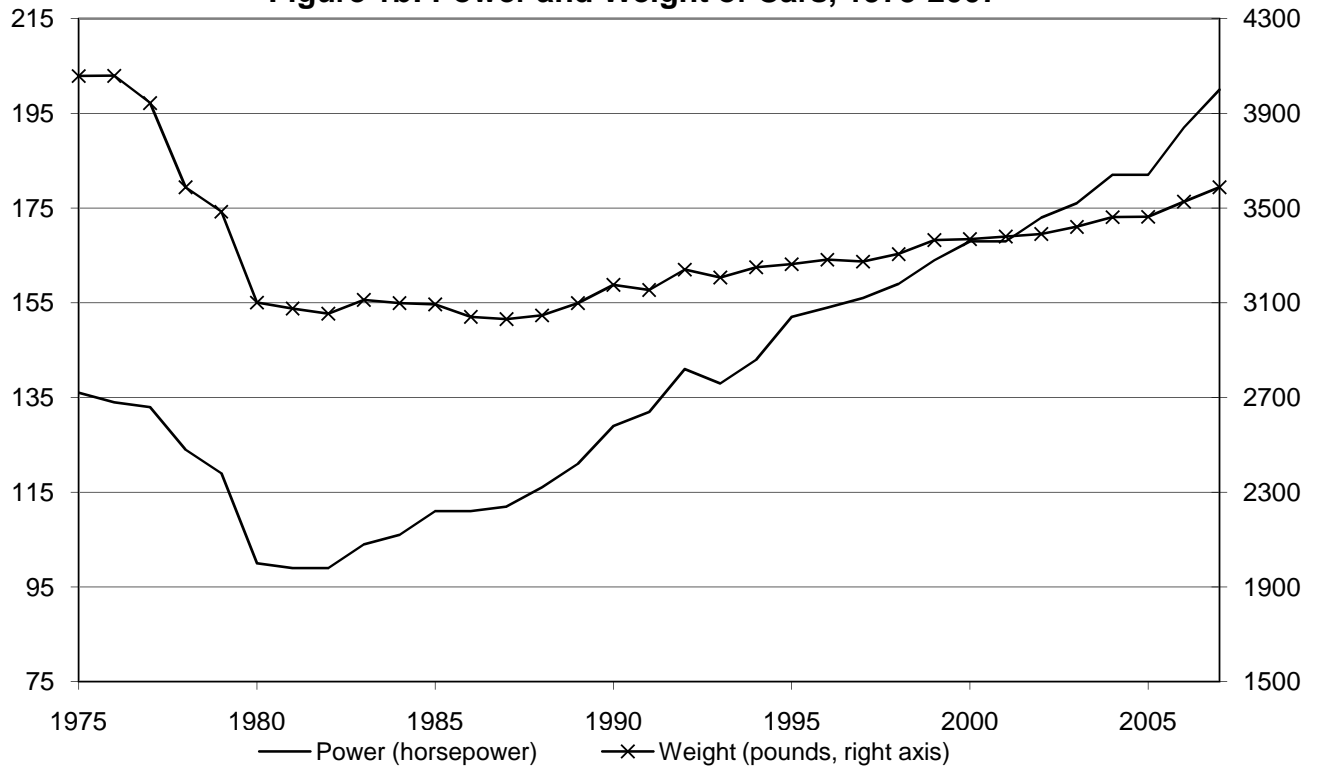
Notes: Figures are constructed using data reported in U.S. EPA (2007).

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

Fuel Economy (MPG) ◆ — Weight (Pounds) ■ — Power (Horsepower x 10) ▲
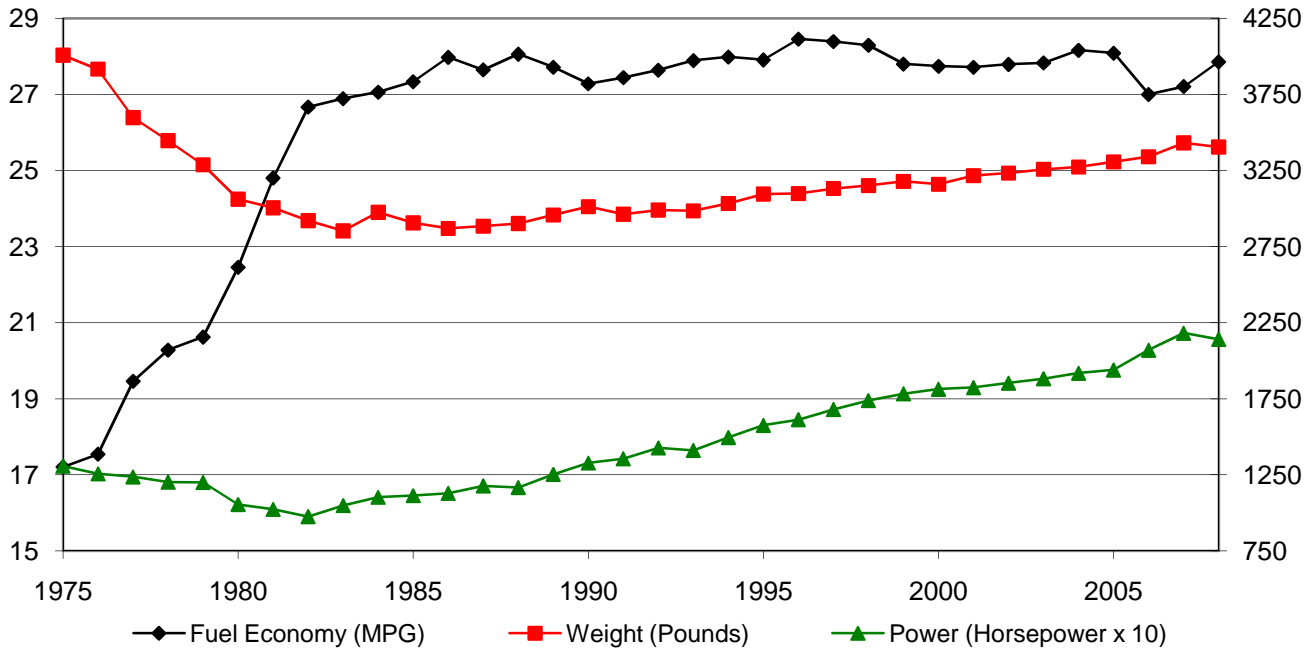
Figure 2b: Change in Fuel Efficiency, Weight and Power, 1975-2008

Fuel Economy ◆ — Weight ■ — Power ▲
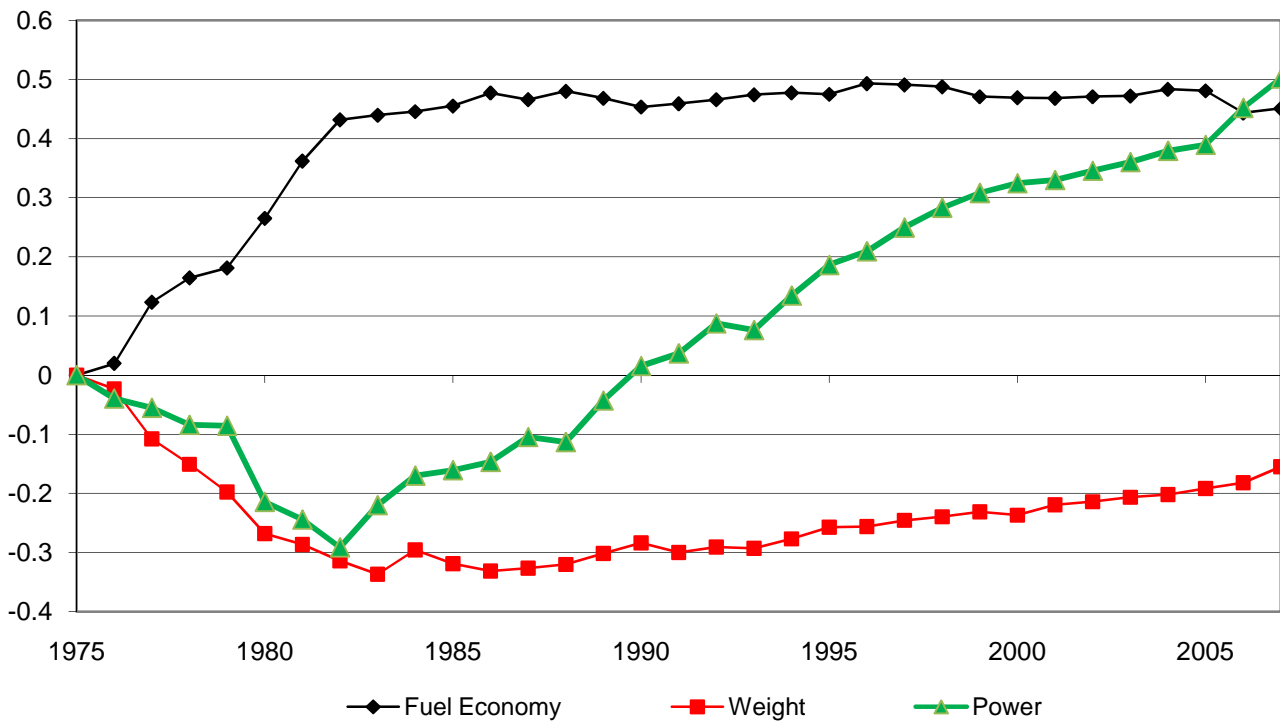
Notes: Figure 2a reports the sales-weighted mean fuel economy (in MPG), weight (in pounds) and horsepower (multiplied by 10) of all cars sold by U.S. companies for each year. Figure 2b reports the percent change in each variable, relative to 1975.

**Figure 3: The Effect of Changes in Sales and Fuel Efficiency,
Balanced Panel of U.S. Cars, 1975-1984**
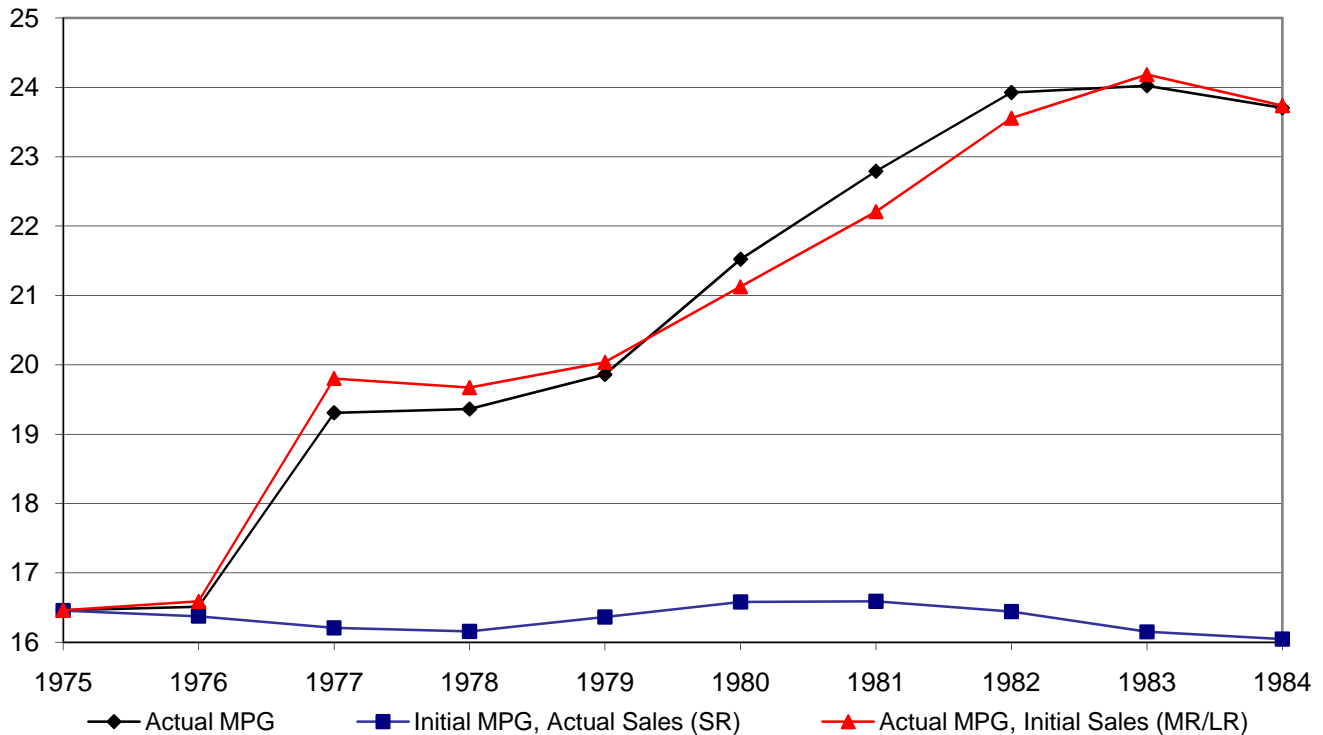
Notes: Actual MPG is the sales-weighted mean MPG of all cars sold by U.S. firms that have positive sales for each year, 1975-1984. The initial MPG series is the sum of the actual MPG in 1975 and the inner product of the change in sales weights and the 1975 MPG of each vehicle model. The actual MPG series is the sum of the actual MPG in 1975 and the inner product of the change in MPG of each vehicle model with the 1975 sales weight. See text for details.

Figure 4: Effect of Power and Weight on Fuel Efficiency for U.S. Manufacturers, 1975-2008
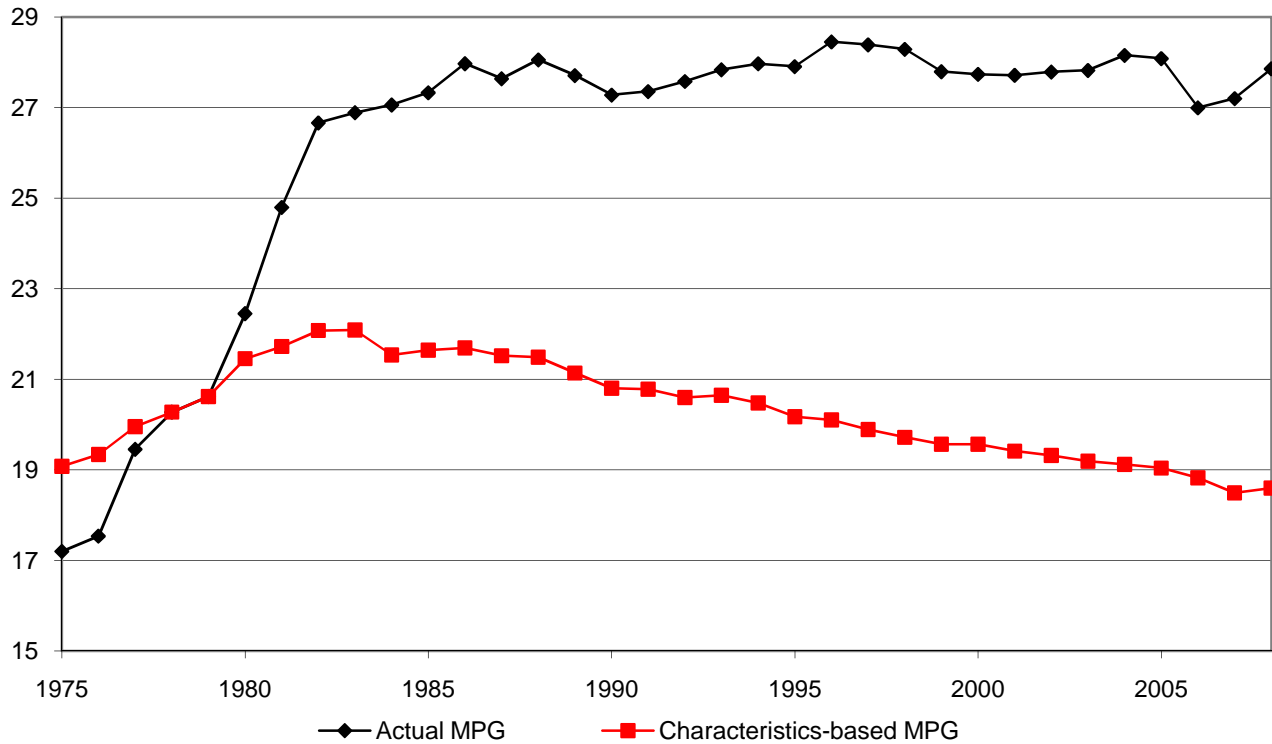
Notes: The actual MPG series is the same series as reported in Figure 2. The change in predicted MPG is calculated using equation (1), the estimated coefficients reported in column 1 of Table 2 and the change in sales-weighted power and weight from Figure 2. The characteristics-based MPG is equal to the sum of the actual MPG in 1978 and the change in predicted MPG.

Figure 5: Change in Willingness-to-Pay Due to Changing Vehicle Characteristics for U.S. Firms, 1975-2008
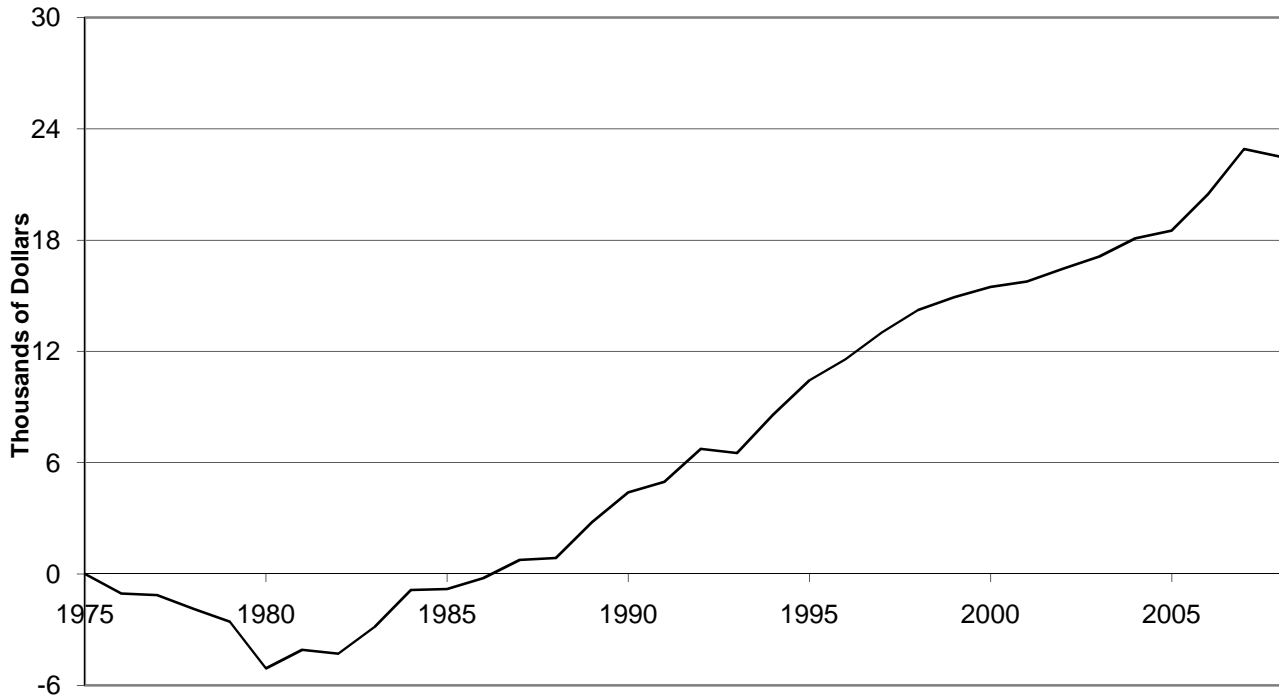
Notes: The figure plots the change in willingess-to-pay for U.S. cars, using 1975 as the baseline year. Change in willingness-to-pay is calculated using the change in sales-weighted power and weight from Figure 2 and the estimates from column 3 of Table 5.

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