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HOW CAFE INFLUENCES AUTO FIRMS AND CONSUMERS? — USING EVIDENCE FROM U.S. MARKET

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Abstract

This paper examines how the CAFE regulation influences the auto firms' behavior and the consumers' behavior. To be specific, I examine the influence of CAFE on three groups of auto firms' pricing and production decision as well as the influence on consumers' consumption decision on model choice and the vehicle miles to travel. Through estimating the simultaneous production and pricing equation system for firm, the paper indicates that previous literature that estimates the supply equation separately for each firm is misleading and CAFE regulation has different effects on unconstrained group, constrained group and fine-paying group through different channels. Also the CAFE regulation affects the consumer behavior since CAFE has unbalanced effects on prices of different auto models.

Keywords: CAFE, Firm Behavior, Consumer Behavior, Pricing Strategy, Production Strategy, Simultaneous Equation System

1. Introduction

This paper aims to analyze the influence of CAFE (Corporate Average Fuel Economy) influence the auto firms and the consumer so that we can get a general idea about how the CAFE policy affect the social welfare. It is quite important for the government know how the policy works to improve the social welfare since improper policy instrument might reduce the total welfare. Also, for the auto firms, it is necessary to know how to adjust the production and pricing strategies to adapt to policy regulation to maximize firms' profit. For the consumers, so long as the pricing strategy for different auto model types change, the consumption decision about the model choice should also change, correspondingly.

CAFE policy is the most important policy instrument in the automobile industry. The CAFE is first enacted by the U.S. Congress in 1975. CAFE is intended for improving the average fuel economy of cars and light trucks (trucks, vans and sport utility vehicles) sold in the US in the wake of the 1973 Arab Oil Embargo. Historically, it is defined as sales-weighted fuel economy, which is expressed in miles per US gallon (mpg). This include a manufacturer's fleet of current model year passenger cars or light trucks with a gross vehicle weight rating (GVWR) of 8,500 pounds (3,856 kg) or less that are manufactured for sale in the US. If the MPG falls below the CAFE threshold, the manufacturer must pay a penalty, currently $5.50 per 0.1 MPG per vehicle. In addition, a Gas Guzzler Tax is levied on individual passenger car model (but not trucks, vans, minivans, or SUVs) that gets less than 22.5 miles per US gallon (10.5 l/100 km). But this paper does not take Gas Guzzler Tax into consideration.The National Highway Traffic Safety Administration (NHTSA) regulates CAFE standard and the US Environmental Protection Agency (EPA) measures MPG. However, the small market share automobile firms are exempted from the CAFE regulation and given additional standard for passenger car fleet and light truck fleet.

There have already been quite a lot studies that analyze the policy effect on the automobile industry. Parry *et al.* (2007) compared gasoline tax with CAFE policy and found that gasoline tax has less externality than CAFE regulation. Goldberg (1998) analyzed the relationship between international trade and CAFE in the Oligopoly market, emphasizing the auto firms' response to the CAFE regulation. Similarly, Greene (1991), Anderson and Sallee (2011) showed how firm behavior change under CAFE. So these papers only talked about the CAFE's influence on auto firm, not including the demand side reaction. Jacobsen (2013) build up a relative comprehensive model including both the demand side and supply side. However, it does not develop a solid theoretical basis for empirical work. Also it use the same estimation strategy for different auto firms, this might be invalid. And I will show later that different auto groups should be estimated differently. One common point for all above literature is that these papers do not consider the interaction between the pricing strategies among different models. They estimate the pricing equations separately for each firm. However, in my theoretical model, I will show that due to the competition relationship, the firms' pricing strategy should be interacted with each other so that we cannot estimate the supply equation separately but simultaneously.

The CAFE policy influences the production strategies for the auto firms since they adjust the auto models characteristics to comply with the CAFE regulation. For instance, the auto firms might change the horse power and curve-weight to reach certain level of MPG so that they comply with the CAFE standard and avoid the penalty fees. However, different auto firms have different compliance status in the time period that we analyze. Generally speaking, there are three groups of auto firms, divided by their compliance status (or the actual MPG). The first group is called "unconstrained group". This group auto firms have high MPG in the passenger car fleet and light truck fleet so that the regulation do not have direct effect on them. The CAFE policy affects such group through improving the competition position. The second group is "constrained group". The auto firms in this group, such as Ford, use the banking and crediting or improving the MPG to realize the compliance of the CAFE. So, CAFE influenced the constrained group directly since it influence the production decision of the firms. The third group is "fine-paying group", such as BMW. For this group, the auto firms choose to pay fine to comply with CAFE. So, CAFE directly increases cost for the third group. In this sense, it is necessary to divide the auto firms into three groups, which is similar to Jacobsen (2013). However, Jacobsen (2013) does not take into consideration of the different channels through which the CAFE influence the three groups and then the theoretical and empirical framework is not considerable which will be shown in my paper.

Berry *et al.*(1995) generated a theory framework to study the equilibrium price through analyzing demand and supply in the differentiated automotive industry. They provide an extended discrete choice model to analyze the demand and supply bilateral relationship in the automotive market. I followed the main structure in Berry *et al.*(1995) and construct a discrete choice model by categorize all auto models into 24 models. However, different from Berry *et al.* (1995) and Jacobsen (2013), I assume that the auto firms can also decide the model MPG as well as the model price instead of only deciding the model price. This framework is more flexible and realistic compared to previous literature due to the reasons that we have discussed in last paragraph. So, one innovation of my paper is that I assume that under CAFE policy, the auto firms choose both the MPG and price of the auto models to maximize their profits in the Bertrand Market. Also I will provide one comprehensive theoretical model to show why for the constrained group, it is necessary to decide the MPG together with the production quantity.

It is quite intuitive that the pricing strategy changes naturally lead to the consumers' purchase change in the auto model choice. Also since the auto model choice is correlated with the vehicle miles to travel. It is reasonable that the CAFE will make some changes to both the model choice and vehicle miles to travel for the consumers. So, in this paper I build up a simultaneous choice model of the auto model and vehicle miles to travel to take into consideration the whole effect of CAFE on consumer. Similar as supply side, I build up a solid theoretical model to analyze the interactive relationship between model choice and vehicle miles to travel. In the empirical estimation part, I include the gasoline price, distance to work, distance to school as well as the household income as the determinants of vehicle miles to travel. The gasoline influence have been discussed in Ohta and Griliches (1986) and other related studies. In such studies, the gasoline price influences the model choice directly since they do not distinguish between auto model purchase and vehicle miles to travel. The former does not relate to gasoline price while the latter relates to gasoline price. However, in my framework, I distinguish between the model choice and vehicle miles to travel. So gasoline price here serves as a shifter for demand for vehicle miles to travel, instead of shifter for model choice in previous literature. There are a lot of pricing related literature, such as Kutlu and Wang (2015a), Kutlu and Wang (2015b), Wang and Yang (2016a), Wang and Yang (2016b),Wang and Yang (2016c) and Hallberg*et al.* (2014). Wang (2016) discussed the dynamic pricing in the airline industry, which is comparable to automobile industry. Wang *et al.* (2009) show the pricing behavior for the big supermarket which is also Oligopoly market.

The data is collect from many resources. The CAFE data is collected from the government website NHTSA (National highway traffic safety administration), which is dated back to 1978. For the price and quality characteristics and other index for the auto model, we get from self-established automotive database collected from Consumer report: buying guide (from 1990 to 2012). And the survey results are from 1979 to 2011. Also the annual market share for each automotive firm is collected from wardsauto. There is one potential problem with the database due to the availability of detailed database on model level. All quality index data are model-level data, however, the market share data are firm-level data. For the demand side data, we treat household as individual unit. The primary data source is the 2009 National Household Travel Survey (NHTS). It provides household income, household state as well as other demographic data. Also it includes the vehicle types that the household owned and the age of the vehicle. This database contains not only the new vehicles but also the old vehicles. And the price of the old vehicle can be collected from the National Automobile Dealer's Association (NADA) Car Guide.

The expected findings are as follows. For the supply side, I expect that first the autocorrelation between different auto model supply error term exist for most of the models, so that previous studies has ignore this autocorrelation among error terms and then the estimation is not consistent. Secondly, I expect that the stringent of CAFE will lead to no change for the unconstrained firms, increase for the fine-paying firms and constrained firms. Also, the CAFE stringent leads to MPG increase for the constrained firms. For the demand side, it is expected that that there would be model choice change since the price will change for different model due to change in CAFE policy.

The remaining of the paper is as follows. In section II, I develop a comprehensive theoretical model for both the supply side and demand side. In section III, the data that will be used in future sections in described. In section IV, the empirical estimation equations and the expected results are given. In final section, we summarize the whole paper and discuss the innovation, limitation and potential future work.

2. Theoretical Model

In this section, I will develop a comprehensive theoretical model for both the supply side and demand side, aimed at describing the whole influence of CAFE more detailed. I first come up with the supply side theoretical model by dividing all the auto firms into three groups and then analyze the differences among the three groups. Then I continue to analyze the demand side theoretical model.

2.1. Supply Side Theoretical Model

Auto firms are Oligopolists in a differentiated product market. We further assume that the auto firms are Bertrand competitors since they decide their product prices to compete with other auto firms. To simplify the estimation, we also assume that firm's pricing strategies are consistent over time in different characteristics of autos. That is, when making price strategy, the weight put one certain model characteristics are fixed for certain firm across the years.

CAFE standards influence the auto firms in two ways. Firstly, if the auto firm violates the CAFE standards either in the passenger car fleet, it will be imposed a civil penalty of $5.50 for each 0.1 MPG per vehicle produced (U.S.C. 32912(b)).Credits earned from exceeding the standard in any of the three model years immediately before or after the model year, can be used to offset the penalty. Secondly, for the auto firms that comply with the CAFE standard, some R&D cost might be involved to improve the fuel efficiency of the auto models.

From this aspect, it would be easier for the interpretation when we divide all the auto firms under CAFE regulation into three groups: that firms that are not constrained by the regulation, the firms that are constrained by the CAFE regulation and do not pay the fines either using banking or borrowing of the credit or investment in R&D as well as the firms that is "constrained" by the CAFE but pay the violation fines. For the unconstrained group, the regulation do not directly influence the price since it does not expose any restriction to such firms, such as Honda and Toyota whose MPG is always higher than CAFE standard. However, the CAFE standard will indirectly influence the unconstrained auto firms since the CAFE regulation impose additional cost on the latter two groups of auto firms, thus indirectly influence the unconstrained auto firms. If the auto firms comply with the CAFE standard though either method, they might transfer their additional cost on the consumer through resetting the price. Also for the constrained firms that use borrow and banking of the credit, there is additionally constrain when the firms make pricing strategies.

Assume further that the auto firms are profit maximizers under the CAFE regulation, solving

$$Max\Pi_i\{p_{ij}, mpg_{ij}, I_F\} = \{\sum_{j\in J}(p_{ij}(X_{ij}) - c_{ij}(X_{ij}))s_{ij}(P)Q - I_{F_i}F_0 s_i(P)Q\}$$

$$s.t.$$

$$I_{C_i}\{\frac{\sum_{j\in carfleet} q_{ij}(p)}{\sum_{j\in carfleet}\frac{q_{ij}(p)}{mpg_{ij}}} - a_{carfleet}\} \geq 0$$

$$I_{C_i}\{\frac{\sum_{j\in truckfleet} q_{ij}(p)}{\sum_{j\in truckfleet}\frac{q_{ij}(p)}{mpg_{ij}}} - a_{truckfleet}\} \geq 0$$

For simplicity we assume the same compliance status of the passenger car and light truck. And this will lead to one potential limitation of my work that I do not consider the case when the firms decide to comply for the passenger car part and pay fines for the light truck, or the other way around. In above equation, j denoted each model and i indexes auto firm. p_{ij} is the price level for model j in firm i. Both the price and the cost of model j depends on the production characteristics of model j, X_{ij}. The market share of model j, s_{ij} depends on all the price of all available auto models, P. The total auto sale is Q. I_{F_i} is an indicator that is equal to one when the firms choose to pay fine, such as BMW and Benz. F_0 is the unit fine paid due to violation of CAFE, which is 5.5 dollars now. s_i is the total market share of auto firm i in the passenger car market and light duty truck market and it also depends on the prices for all models. I_{C_i} indexes whether the firm is constrained by the CAFE standard and tries to comply with CAFE. q_{ij} is the sales of model j in firm i and mpg_{ij} is the Miles Per Gallon for model j. a is the level of the standard for the manufacturer's car fleet and light truck fleet. From here we can see that in the fine-paying group, the constraint does not exist and cost increases since fines are paid. And for the constrained group that do not pay fines, they take the CAFE constrain into consideration when making pricing and production decisions.

What makes my model different from precious literature is that in this model, I assume that the auto firms can also deicide the product characteristics when making producing decisions, especially the mpg level for each model. And this would cause change of price and cost. Previous studies such as Jacobsen (2013) only consider the Bertrand game where the auto firms decide the price for each model. What is more, the firm can also decide whether to pay the fines or to complyCAFE to make profit optimized. From here we can see that when the market share of firm i is relatively small, it is more likely that firm i will choose to pay fine rather than invest in R&D to comply with CAFE standard. Also we consider the correlation between price and product characteristics, including mpg as well as the cost's correlation with product characteristics. To keep things simple, we further assume that the auto firms can decide the mark-up for each model, that is

$$\underset{\{p_{ij}, j\in J\}}{Max}\,\Pi_i\{m_{ij}, mpg_{ij}, I_F\} = \{\sum_{j\in J} m_{ij}(X_{ij})s_{ij}(P)Q - I_{F_i}F_0 s_i(P)Q\}$$

$$s.t.$$

$$I_{C_i}\{\frac{\sum_{j\in carfleet} q_{ij}(p)}{\sum_{j\in carfleet}\frac{q_{ij}(p)}{mpg_{ij}}} - a_{carfleet}\} \geq 0$$

$$I_{C_i}\{\frac{\sum_{j\in truckfleet} q_{ij}(p)}{\sum_{j\in truckfleet}\frac{q_{ij}(p)}{mpg_{ij}}} - a_{truckfleet}\} \geq 0$$

Here $m = p - c$ denotes the price markup. To optimize profit in the Bertrand market, we need

$$\frac{\partial \Pi_i}{\partial p_{ij}} + \lambda I_{C_i}\frac{\partial\{\frac{\sum_{j\in carfleet} q_{ij}(P)}{\sum_{j\in carfleet}\frac{q_{ij}(P)}{mpg_{ij}}} - a_{carfleet}\}}{\partial p_{ij}} + \mu I_{C_i}\frac{\partial\{\frac{\sum_{j\in truckfleet} q_{ij}(p)}{\sum_{j\in truckfleet}\frac{q_{ij}(p)}{mpg_{ij}}} - a_{truckfleet}\}}{\partial p_{ij}} = 0$$

and,

$$\frac{\partial \Pi_i}{\partial mpg_{ij}} + \lambda I_{C_i} \frac{\partial\{\frac{\sum_{j\in carfleet} q_{ij}(P)}{\sum_{j\in carfleet}\frac{q_{ij}(P)}{mpg_{ij}}} - a_{carfleet}\}}{\partial mpg_{ij}} + \mu I_{C_i} \frac{\partial\{\frac{\sum_{j\in truckfleet} q_{ij}(p)}{\sum_{j\in truckfleet}\frac{q_{ij}(p)}{mpg_{ij}}} - a_{truckfleet}\}}{\partial mpg_{ij}} = 0$$

and,

$\Pi_i(I_{F_i}=1) \geq \Pi_i(I_{F_i}=0)$ if $I_{F_i}=1$ & $\Pi_i(I_{F_i}=1) \leq \Pi_i(I_{F_i}=0)$ if $I_{F_i}=0$

Here λ is the shadow cost of increasing one unit passenger car CAFE standard and μ is the shadow cost of increasing one unit light duty truck CAFE standard. From above three conditions, we derive the price for each model as a function of all the product characteristics (including mpg) and the compliance status of the firm. In other words, the optimized firm behavior can be given as $p_{ij} = p_{ij}(X_{ij}, I_{F_i}, I_{C_i}, P^-)$ for all three groups and $mpg_{ij} = mpg_{ij}(X_{ij}, I_{F_i}, I_{C_i}, p_{ij}, P^-)$ for constrained firm only.

From the equation we can see that the price of model j depends on firm i's decision as well as other firm's price level, P^-. So in the empirical part, we should not estimate the supply equation separately for each model since the price is correlated with each other. However, it is common to estimate the price equation separately in previous literature (e.g., Austin and T. Dinan (2005), Anderson and Sallee (2011) and etc). Also we should note here that the compliance status is an importance factor that determines the price level so in the empirical part I will estimate the three groups separately to get the effect of CAFE standard.

2.2. Demand Side Theoretical Model

In this paper, we assume that the consumers make simultaneous decisions on the auto model choice and the VMT (vehicle miles to travel) to maximize their utility level. Here we assume that the consumer k's utility is given by

$$Max_{M_k, VMT_k} U_k = U(M_k, VMT_k, m_k^o) = (M_k(VMT_k) + \theta_k VMT_k(M_k))^{\alpha} m_k^{o(1-\alpha)}$$

We assume that the consumer utility level is concave in the vehicle choice, M_k and the vehicle miles to travel, VMT_k as well as consumption of composite good m_k^o. Different consumer put different weight on Vehicle Miles to Travel relative to Model choice, denoted as θ_k. Also in this model, we assume that the choice of auto model depends, somewhat, on the Vehicle Miles to Travel because it is likely that when the Vehicle Miles to Travel is relatively high, the consumer is more likely to choose the high MPG auto. Also it is common to have several autos in one household, so it is more likely to use the auto model that have relatively high MPG for travel, then it is natural that the Miles on the model also depends on the model. From another aspect, we can view the choice of model as investment of fixed cost and the Vehicle Miles to Travel as variable cost. But different from normal fixed cost and variable cost relationship, this “fixed cost” and “variable cost” are correlated to each other.

The budget constrain for the consumer k is $p_{ik}M_k + \sum p_g VMT_{kt} + m_k^o = I_k$. p_g is the gasoline price in time t. I_k is the consumer income. From here we derive $m_k^o = I_k - p_{ik}M_k - \sum \rho_t VMT_{kt}$ and take this into utility function, we can get $U(VMT_{k,} M_k, I_k)$.

Maximize consumer's utility level, we get $\frac{\partial U(VMT_{k,} M_k, I_k)}{\partial VMT_k} = 0$ and $U_i(VMT_{k,} M_k, I_k) \geq U_i(VMT_{k,} M_l, I_k)$ for any alternative model l. So in the equilibrium, we have $VMT_k = VMT(I_k, M_k)$ and $M_k = M(I_k, VMT_k)$.

In summary, in the theoretical part, I build up a theoretical model to estimate the CAFE standard effect on both the supply side and the demand side. And the CAFE standard influences the three groups of auto firms directly or indirectly. Also this theoretical framework suggests that we should estimate the price equation of different models together instead of separately. Also the MPG decision is endogenous; we can estimate it through simultaneous equation system or finding a proper instrument for MPG and estimate through simple 2SLS. As for the demand side, the optimization of utility indicates that consumer confronts with simultaneous decision on model choice and Vehicle Miles to Travel. So it would be proper if we estimate it through simultaneous equation system.

3. Data

The data for regulation policy is mainly the CAFE standards. CAFE standards are enforced at the fleet level in a given model year. Each manufacturer's production is divided into two separately fleets: passenger cars and light duty trucks. But CAFE regulation considers exemptions for low volume manufacturers (those producing fewer than 10,000 passenger cars annually worldwide) and establishes alternative standards for them. So in my studies, I eliminate all the small auto firms. The data can be easily collected from the government website NHTSA (National highway traffic safety administration). From here, we get the dynamic change of the CAFE standards from 1978 to now. The standard in 2009 was 27.5 MPG for passenger cars and 23.1 MPG for light duty trucks. And the standards slightly increase through the timeline. It includes the information on individual firm compliance status, fines paid if auto firms violate the CAFE standard as well as the CAFE standard for the passenger car fleet and light truck fleet in each year from 1970s to 2004. Also it reports the MPG of models for different auto firms. The summary of CAFE is given in Figure 1. From Figure 1, we can see that there are sharp increases in the earlier year before 1985, followed by a sharp decrease in CAFE levels and then increase again and little change in recent years for the passenger car fleet. Similar change patterns exist for the truck fleet, however, the car fleet experiences increasing CAFE standards in recent years. In the earlier years, CAFE has separate standards for the two-wheel and four-wheel drive truck as well as standard for the whole light truck fleet. The auto firms can choose either to comply with the separate CAFE standard for both two-wheel and four-wheel drive truck or comply with the whole light truck fleet standard. Also, I want to point out that during 1998 to 2004, the CAFE standards slightly and steadily increase over time. However, the change is not big enough, so we can only see the flat trend in recent years.

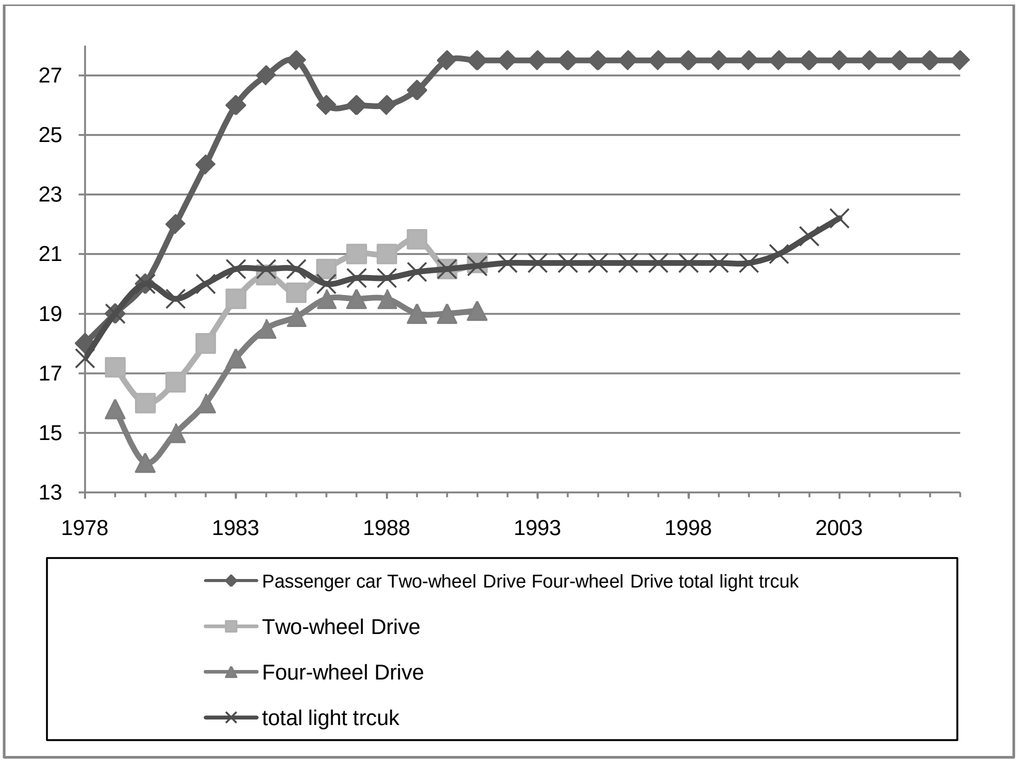

Figure 1. CAFE Standard from 1978 to 2007
Source: NHTSA

For the price and quality characteristics and other index for the auto model, we get from self-established automotive database collected from Consumer report: buying guide (from 1980 to 2012). And the survey results are from 1979 to 2011. We manually input the quality index data, which includes the overall road test score (average score from the several model road test), the owner satisfactions (satisfaction level of the automotive owner), the weighted MPG (miles per gallon) as an index of fuel economy, predicted reliability (predict of how well a new car will likely hold up based on previous Annual Auto Survey), owner cost (a rating of the five-year projected cost to own a vehicle, including depreciation, fuel interest, insurance, maintenance/repair and sales tax), safety (an overall score based on the combination of crash test and accident avoidance results). All above indexes are ranked in the consumer report as “good”, “above average”, “average”, “below average” and “bad”. And in this paper, we transform all the ranks into grades 5, 4, 3, 2, 1 into the database. The dependent variable, price of each model, is also from Consumer report: buying guide. In addition to the index and price, we also include the firm as well as the model and the size, type into the database for further detailed analysis. Also the annual market share for each automotive firm is collected from wardsauto. There is one potential problem with the database due to the availability of detailed database on model level. All quality index data are model-level data; however, the market share data are firm-level data. In order to simplify the problem, we just assume that the firm-level market share can be divided equally to each model in that firm, neglecting the potential imbalance in the market share among different models.

We can get some general idea about how CAFE standard change the firm production behavior in Figure 2, 3. From Figure 2 and 3, we can see that the manufacturing adjust their MPG according to the CAFE regulations.

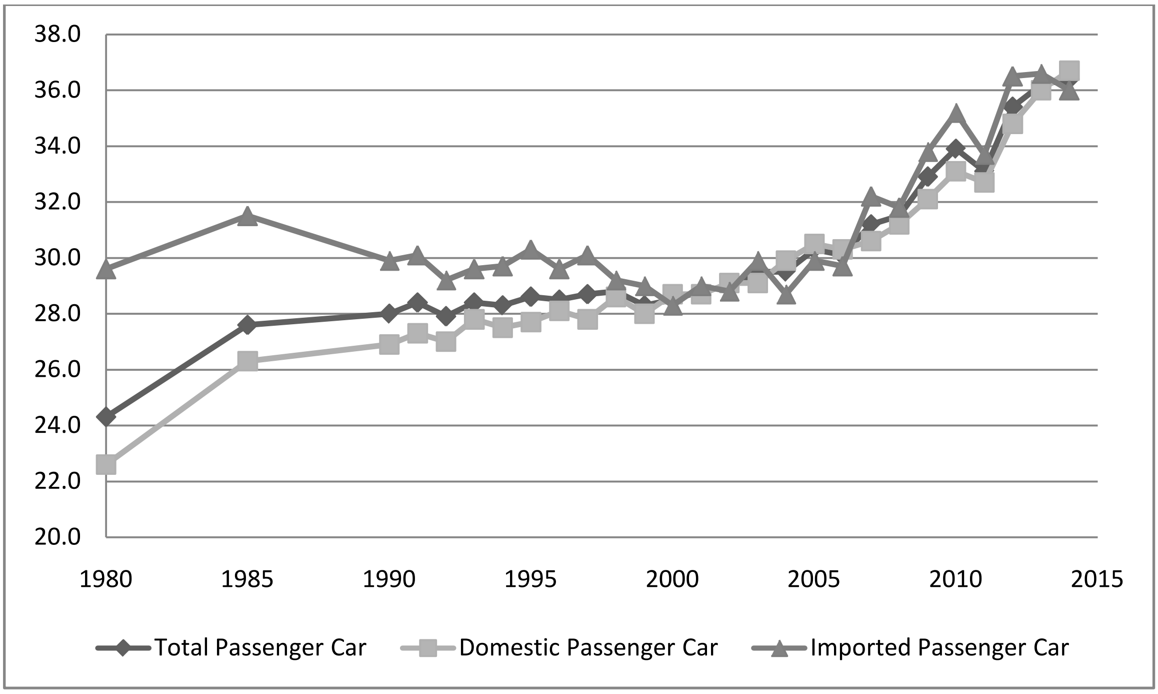

Figure 2. Sale Weighted MPG Change for the Passenger Cars
Source: NHTSA

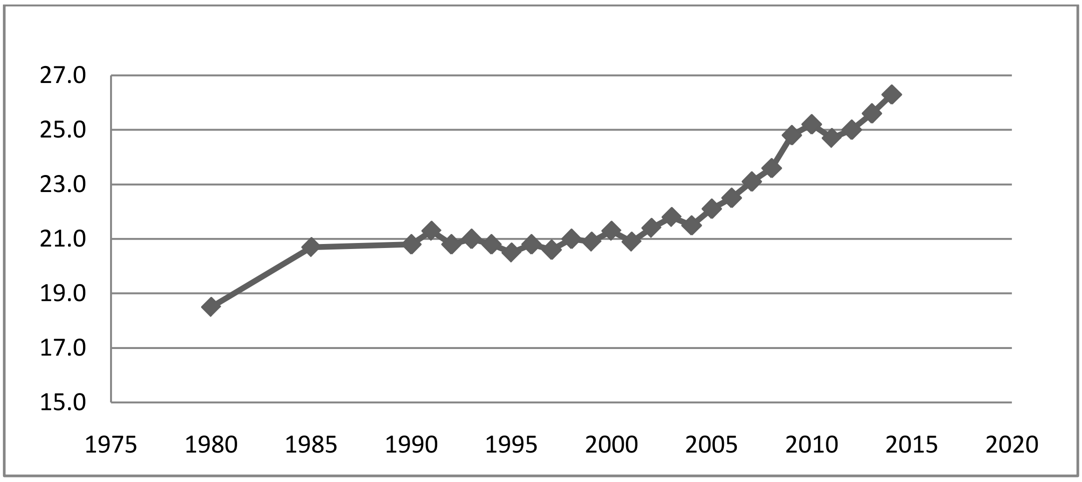

Figure 3. Sale Weighted Change of MPG for Light Truck
Note: Light Truck (<8,500 lbs GVWR)
Source: NHTSA

The influences of CAFE on different types of automobile are different. We can get some idea from the market share change of automobiles to understand the different effects. So it is necessary for us to categorize the autos into several categories. The red ones are passenger car types and the blue ones are truck types. This table shows how the market shares of different types change when the CAFE standard increases from 2003 to 2004. Overall, Table 1 reflects a continuing trend toward heavier cars for the passenger car.

Table 1. The change in production quantity by auto types

Segmentation by EPA Size Class (%)	2003	2004	Total Change
Two-Seater	2.3	2.3	0
Mini-compact	1.8	1.5	-0.3
Subcompact	5.4	6.7	1.3
Compact	39.7	37.5	-2.2
Mid-Size	34.8	36	1.2
Large	16.2	17	0.8
Passenger Van	13.4	9.3	-4.1
Cargo Van	1.5	0.8	-0.7
Small Pickup	1.8	0.1	-1.7
Large Pickup	16.1	16	-0.1

Source: NHTSA

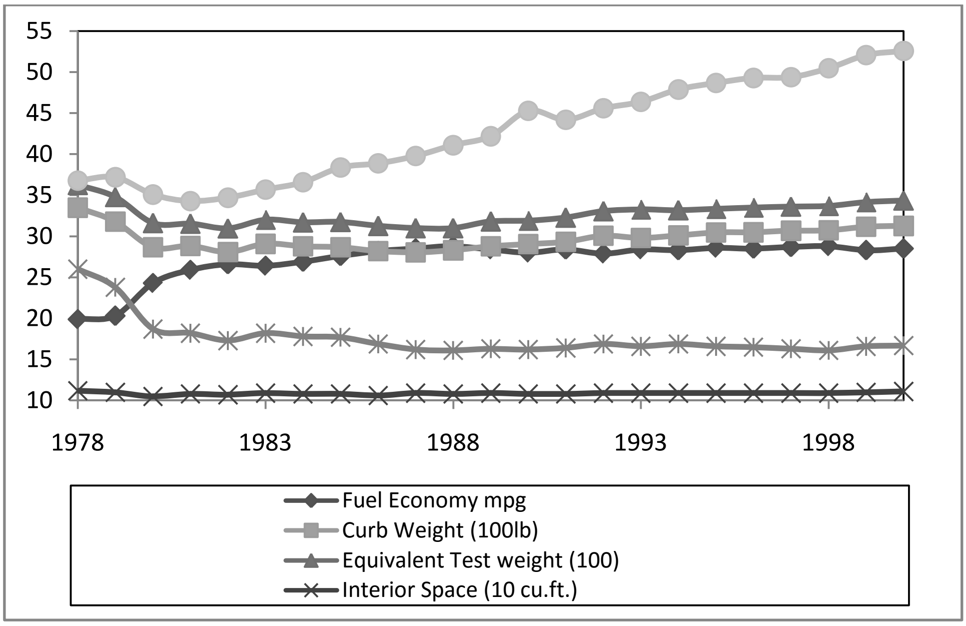

Figure 4. Passenger Car Characteristic Changes
Source: NHTSA

We can get some intuitions that firm do adjust their production strategies under CAFE. However, the pervious literature do not consider about this. From Figure 4, we can see that the MPG goes up in earlier years and remain somewhat stable in recent years. Other model characteristics also change correspondingly. However, it is not necessary that all the auto firms try to comply with the CAFE regulation. According to the 2004 report, seven passenger car manufacturers (BMW, DaimlerChrysler import, Ferrari/Maserati, Ford domestic, Lotus, Porsche, and Subaru) and four light truck manufacturers (DaimlerChrysler, Kia, Porsche, and Volkswagen) failed to meet CAFE standards. Several of these manufacturers will not pay civil penalties because credits they earned by exceeding the fuel economy standards in earlier years will offset the MY 2004 shortfalls. These manufacturers either pay civil penalties or file carryback plans to demonstrate that they anticipate earning credits in future model years to offset current credit deficits. In this way, it would be necessary to divide the auto firms into three categories according to their compliance status, which corresponds to the theoretical framework.

For the demand side data, we treat household as individual unit. The primary data source is the 2009 National Household Travel Survey (NHTS). It provides household income, household state as well as other demographic data. Also it includes the vehicle types that the household owned and the age of the vehicle. This database contains not only the new vehicles but also the old vehicles. So it is quite comprehensive. And the price of the old vehicle can be collected from the National Automobile Dealer's Association (NADA) Car Guide. For the energy price, we include the gasoline price into the model since the majority of the automobile is using gasoline. In the main context, I focus on the new car purchases; however, I will analyze both the used car and new car in the robustness check.

4. Empirical Framework

In this section I will develop an empirical framework so that we can estimate the supply side and demand side. I begin with the estimation of firm behavior.

4.1. Empirical Estimation for the Demand Side

From the theoretical section, we get some intuition for the empirical estimation. Similarly, we first divide the auto firms into three different groups according to their compliance status and passenger car's fleet MPG and light truck fleet MPG. The first group is unconstrained auto firms, which is defined by the MPG exceeds the CAFE standard for every year such as Toyota and Honda. The second group is constrained group, which is defined by the MPG exceeds the CAFE standard for some years while falls below CAFE standard for other years such that no fine is paid such as Ford and GM. The third group is fine-paying auto firms, which is defined by the MPG is far below the CAFE standard and the auto firms pay the fines for this violation, such as BMW.

After dividing the auto firms into three distinct categories, we estimate the three groups separately. For the unconstrained group and the fine-paying group, we estimate the following equation1

$$\ln p_{ijt} = \beta_{it} + \beta_{1i} \ln mpg_{ijt} + X_{-ijt}\beta_{-i} + \alpha \ln P_{-ijt} + \gamma \ln CAFE_t + \varepsilon_{ijt}$$

$$\ln p_{klt} = \beta_{kt} + \beta_{1k} \ln mpg_{klt} + X_{-klt}\beta_{-k} + \alpha \ln P_{-klt} + \gamma \ln CAFE_t + \varepsilon_{klt} \text{ for } k \neq i \text{ or } j \neq l$$

p_{ijt} is the price for firm i model j in year t and this price term is deflated by the Consumer Price Index in year t of auto model year. β_{it} is the firm fixed effect and is allowed to vary among across firms and time. This can somewhat measures the firm's brand effect as well as year fixed effect. mpg_{ijt} is the MPG for firm i model j. X_{-ijt} includes all other product characteristics, including engine size, transmission and other characteristics. P_{-ijt} is the price index for all other auto models. $CAFE_t$ is the CAFE standard in the model year. ε_{ijt} is the error term, which is assumed to be uncorrelated with $CAFE_t$. It is reasonable to assume that $CAFE_t$ is exogenous variable here. The omitted variable here include the dealer's information and other factors that influence price but are believed not to correlated with policy decision on $CAFE_t$. Furthermore, in order to get the consistent estimation of $CAFE_t$, we need further assumption about the error term. The error term among different equations should be correlated with each other, $Cov(\varepsilon_{ijt}, \varepsilon_{klt}) \neq 0$ for any $k \neq i$ or $j \neq l$. So we use Cochrane-Orcutt method for

[1] I want to note here, the database is treated as cross-sectional data, the reason that I index time t here is that I treat same model in different years as different observations. Same for all other equations.

autocorrelation among the error terms. Also, to validate our assumption about this error term autocorrelation, we also use standard simultaneous equation system to get the estimation of these two equations based on alternative assumption of $Cov(\varepsilon_{ijt}, \varepsilon_{klt}) = 0$. And here we use the D-W test to compare the two results. I expect that the results are different so that there is autocorrelation between the omitted variable. Based on this finding, previous studies on automobile industries might have some bias since they do not take the autocorrelation between different models into consideration.

I focus on the parameter for CAFE level, which is how the CAFE standard change affects the price change. Since the dependent variable price is in natural log form and the independent variable CAFE is also in log form, we can take the parameter γ as the elasticity of price with respect to CAFE standard. In other words, it measures the percentage change in price with one percentage stringent of CAFE standard.

Since in each equation, we have exogenous variables, auto model specific characteristics, so we do not need to worry about the identification of the equations. However, the difficulty lies in how to define the model. Previous studies do not talk the details about how to divide the different models into several distinct model categories. Here I try to categorize the different models by their product characteristics. I include the engine size(small engine, middle engine, big engine), type (compact, luxury compact, middle size, full size, luxury mid/full-size, SUV, Truck, Minivan), and MPG (high MPG, median MPG, low MPG) to divide all the different auto models into 3*3*8=72 categories. However, usually the type of the automobile determines the engine size and other characteristics of automobile. In other words, it is not common that a SUV has smaller engine than a middle size passenger car. Thus, we just categorize the models by type and MPG. There are 24 categories for the auto models in my model.

Also I have to point out that the database is time series data, however, we do not use it as panel data, and we only use it as cross-sectional data. The reason why I denote the year t is to help identify the policy standard associated with time and the time fixed effect. Also for the same model, indifferent years, we have different retail price. And we treat this as two separate observations in the regression. Also we run the regression separately for the unconstrained group and the find-paying group.

For the constrained group that does not pay fines, we take the strategy of simultaneous decision on price and MPG, based on the theoretical model. And this part is totally different from previous literature. The estimation equation is given by

$$\ln p_{ijt} = \beta_{it} + \beta_{1i} \ln mpg_{ijt} + X_{-ijt}\beta_{-i} + \alpha \ln P_{-ijt} + \gamma \ln CAFE_t + \varepsilon_{ijt}$$

$$\ln mpg_{ijt} = \beta^{'}_{it} + \beta^{'}_{1i} \ln p_{ijt} + X_{-ijt}\beta^{'}_{-i} + \alpha^{'} \ln P_{-ijt} + \gamma' \ln CAFE_t + \varepsilon^{'}_{ijt}$$

$$\ln p_{klt} = \beta_{kt} + \beta_{1k} \ln mpg_{klt} + X_{-klt}\beta_{-k} + \alpha \ln P_{-klt} + \gamma \ln CAFE_t + \varepsilon_{klt}$$

$$\ln mpg_{kjt} = \beta^{'}_{kt} + \beta^{'}_{1k} \ln p_{kjt} + X_{-kjt}\beta^{'}_{-k} + \alpha^{'} \ln P_{-kjt} + \gamma' \ln CAFE_t + \varepsilon^{'}_{kjt} \text{ for } k \neq i \text{ or } j \neq l$$

Just taking look at the first two equations, we need additional instruments to estimate the equations. And it is difficult to find suitable IV for estimation. However, we can identify the two equations when we use the whole equation system as simultaneous equation system since there are always sufficient instruments of other models' characteristics to identify each equation. Similarly, we allow for the autocorrelation between the error terms and use the Cochrane-Orcutt method to estimate.

4.2. Expected Results for Supply Side

I expect that first the autocorrelation between different auto model supply error term exist for most of the models, so that previous studies has ignore this autocorrelation among error terms and then the estimation is not consistent. Secondly, I expect that the stringent of CAFE will lead to no production change for the unconstrained firms, price increase for the fine-paying firms and constrained firms. Since for the constrained firm, they might invest a little bit R&D to comply with the CAFE standards. And this will lead to the cost increase in production. For the fine-paying group, CAFE directly increases cost since this group of auto firms pay fines and this cost increases will transfer to the consumer. Due to the improvement in the Bertrand market competition, the unconstrained firm might also increase their model prices. Also, the CAFE stringent leads to MPG increase for the constrained firms. Finally, it is expected that the production change and price change for different auto models are unbalanced.

4.3. Empirical Estimation for the Demand Side

For the demand side, based on the theoretical framework, we develop a simultaneous decision of Vehicle Miles to Travel and Model choice, that is

$$VMT_j = \delta M_j + \delta_2 p_{g_j} + \delta_3 dist_w + \delta_4 dist_s + \delta_5 I_j + \mu_j$$
$$M_j = \eta VMT_j + \delta'_2 p_{g_j} + \delta'_5 I_j + \kappa p_j + \mu'_j$$

M_j is the model indicator. p_{g_j} is the price for gasoline. $dist_w$ is the distance to work and $dist_s$ is the distance to school. I_j is the income for household j. p_j is the price for auto model M_j. From above, we can see that the consumers make simultaneous decision about the auto model and Miles to travel. However, it would be difficult to estimate above equations since the treat a model as dependent variable is a little technically difficult since it is discrete choice model. So we further assume that the model is just an abstract weighted aggregation of different characteristics. That is $M_j = w_1 mpg_j + X_{-j} w_{-1}$. So we have

$$VMT_j = \delta_1 mpg_j + X_{-j}\delta_{-1} + \delta_2 p_{g_{jt}} + \delta_3 dist_w + \delta_4 dist_s + \delta_5 I_j + \mu_j$$

$$mpg_j = X_{-j}\delta_{-1} + \eta VMT_j + \delta'_2 p_{g_{jt}} + \delta'_5 I_j + \kappa p_j + \mu'_j$$

All the variables are aggregated to the household level using the personal weights in NHTS. However, we do not have the concerning about the autocorrelation among different household since the household is decision making unit and we cannot find evidence of cross-household correlation. So we do not need to employ the Cochrane-Orcutt method in this section. To identify the Vehicle Miles to Travel, we need instrument. Since price for auto model is the demand shifter for auto model M_j, not demand shifter for VMT_j, it can serve as the instrument to identify the first equation. As for the model choice equation, the distance to work/school is exogenous variables that both can be used as potential instrument variables. Distance to work and distance to school serves as the demand shifter to the vehicle miles to travel. So, in this simultaneous equation system, the identification problem is solved.

4.4. Expected results for demand side

I expect that that there would be model choice change since the price will change for different model due to change in CAFE policy. The unbalanced change in different auto models will naturally lead to change in consumer behavior. However, we need detailed estimation results to point out what exactly the changes are.

4.5. Potential Robustness Check

Here I provide some potential robustness check once the above estimation is done. First of all, I will change log into level data to estimate and then add in some square term or interaction terms to see whether these results are sensitive to functional form change that we assumed in the paper. What is more, I further side estimate separately using the category of auto models instead of using MPG using logit model for the demand side to see whether there are some changes due to the assumption that the auto model is a weighted aggregate of different model characteristics. Last but not the least, I will enlarge the database for both supply side and demand side to check the robustness. For the supply side, in the main context, I use only the auto firms that have relatively large market share since small auto firms are also under regulated of CAFE. Here I further use only the database that contains the top auto makers and the whole database including also the small auto firms. If the results for the top auto makers are similar to the main results in the paper and the whole database results are different from the main results, we find some evidence of CAFE robust effect. For the demand side, in the main context, I only consider the new car purchase. Here I include both the used automobile and new automobile into consideration to analyze the CAFE's comprehensive effect on the demand side for the used and new vehicles.

5. Conclusions

Through building up a comprehensive model including both demand side and supply side, this paper analyze the effect of CAFE on the auto makers and consumers. For the supply side, it is expected that the autocorrelation among different auto makers exists, so previous studies that estimate the pricing equations separately are invalid. Additionally, CAFE does influence the production decision of the auto firms, so precious literature that neglects the production strategy influence is invalid. And the influences on different types of passenger car and light truck are different. For the demand side, due to the unbalanced pricing strategy change, the consumer behavior also changes.

The main innovation in my paper is that firstly I build up a comprehensive theoretical model for both the supply side and demand side. Also for the supply side, I consider more determinants for the auto firms, the MPG and price, which is more realistic. Also I consider the correlation of the pricing strategies for different auto firms. However, due to the limited time, there are some work that should be done in the future. Firstly, in order to build up a comprehensive cost-and-benefit study for the whole society, we need to get the detailed information on CAFE's influence on consumer surplus and producer surplus. What is more, we need to consider the dynamic situation instead of static situation since there are banking and borrowing for the auto firms. And the most important future work is that I need to estimate the supply and demand system simultaneously in the future. But due to some reasons, I have not got a good idea about how to construct such a comprehensive system. So what I did in this paper is just estimate the supply side and demand side separately.

The main threat to the validity of my estimates is that firstly, the assumptions are too strong. For instance, for the demand side, it is assumed that $M_j = w_1 mpg_j + X_{-j} w_{-1}$. However, it is not the case since the consumers are heterogeneous. So we need a more complicate assumption here. Also we assume that the market share for each model within a firm is equalized. However, this is far beyond reality. However, more detailed model level market share is needed here to relax the assumption. I also believe that there are omitted variables in the estimation equations. However, if more detailed database is available, this problem can be solved.

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