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BEHAVIOR OF AN AUTO FIRM
UNDER THE FUEL ECONOMY CONSTRAINT

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I. Introduction

The oil embargo of 1973-74 focused considerable attention in this country on energy conservation. Legislative proposals appeared almost immediately, many of them dealing with automotive gasoline usage and culminating in the Energy Policy and Conservation Act of 1975. Although most of that legislation dealt with such matters as oil pricing and allocation policies, conversion to nonpetroleum fuels, and energy labeling, one section established annual corporate average mileage standards for vehicles sold by the auto manufacturers. This device was chosen in preference to, e.g., a "gas guzzler" tax in the belief that corporate averages offered flexibility to the manufacturer and a diverse product mix to the consumer. The law specified a sales-weighted average of 18 miles per gallon for the 1978 model year, 19 in 1979, 20 in 1980, and 27.5 in 1985. The standard for the four intervening years was subsequently set by the National Highway Traffic Safety Administration at 22, 24, 26, and 27 miles per gallon.

By steadily increasing the corporate average fuel economy (CAFE) of cars sold, the intent was of course to correspondingly reduce gasoline consumption, at least below what it would otherwise be. The analysis in this paper will show, however, that CAFE alters the price-quantity behavior of the auto manufacturers in particular ways which serve potentially to offset some of the predicted fuel savings even while increasing losses in market efficiency. Indeed, it will be shown possible that induced behavior actually results in an increase in total gasoline consumption under the constraint.

II. Pricing Behavior

The National Highway Traffic Safety Administration has repeatedly emphasized its belief that the mileage standards can be met by technological improvements, particularly weight reduction and changes in engines and transmissions.[1] Some mention is made of the possibility of using prices to shift the mix of cars sold toward high-mileage vehicles, but this strategy is treated as a "safety margin" or a last resort to be used only if the technological improvements are not fully successful.[2] This, however, is not a reasonable assumption about the auto manufacturers' behavior. Given the availability of marketing as well as technological alternatives for meeting the CAFE standards, firms will choose the least-cost combination. It would be surprising if that involved no "mix shift" whatsoever. Furthermore, in the short run (i.e., during a model year), technological changes are infeasible and hence scarcely any alternatives exist to the marketing strategy if planned sales figures are not met.

While considerable attention has been paid by the companies and NHTSA to the costs of the technological approach to meeting CAFE, scarcely any has been devoted to the "mix shift" alternative. The analysis which follows explores the possibility and consequences of the use of prices to alter mix and thereby comply with the standards. The underlying dilemma for the auto manufacturer is that high-mileage cars required to meet CAFE yield lower profit as a result of their greater demand elasticity, while the reverse holds true for low-mileage cars. The analysis which follows models the short-run behavior of an auto firm faced with reconciling the CAFE constraint with profit maximization. In addition, it makes these further assumptions:

(1) There are only two models sold by the firm. "Large" cars get low miles per gallon (M_1) and "small" cars get high mileage ($M_2 > M_1$). The addition of more models complicates the analysis enormously without the benefit of new insights.

(2) Demand curves for the two models are linear and depend both on own price and on the price of the other model:

$$P_i = \alpha_i - \beta_i Q_i + \gamma_i P_j, \quad i,j=1,2; \; j \neq i \qquad (1)$$

where all α_i, β_i, γ_i are positive. As before, the subscript "1" refers to large cars and "2" to small cars. While demand is also a function of mileage, the latter is technologically determined in the short run and should here be interpreted as part of the constant term.

(3) Cars are produced at constant unit cost, C_1 and C_2. Again, in the short run, fixed costs and the possibly different average total costs associated with different mileage cars can be ignored.

(4) The CAFE standard (K), when imposed, binds exactly. That is, no excess average mileage occurs as the result of either risk avoidance by the manufacturer or mileages and demands which lead to a profit-maximizing outcome above the regulatory standard. K is calculated as the harmonic average of the EPA-rated mileages of the units sold:[3]

$$K = \frac{Q_1 + Q_2}{\frac{Q_1}{M_1} + \frac{Q_2}{M_2}} \qquad (2)$$

For the constraint to bind, $M_1 < K < M_2$.

Initially, in the absence of a CAFE constraint, firms maximize

$$\pi = P_1Q_1 + P_2Q_2 - C_1Q_1 - C_2Q_2 \qquad (3)$$

which yields familiar first-order conditions on quantities

$$Q_i^0 = \frac{\alpha_i + \gamma_i P_j - C_i}{2\beta_i}, \quad i,j=1,2;\ j \neq i. \qquad (4)$$

Alternatively when the constraint is imposed and binds exactly, profits (3) must be maximized subject to (2). Differentiating the appropriate Lagrangian yields the optimum quantity of large cars

$$Q_1^* = \frac{(\alpha_1+\gamma_1P_2-C_1)+R(\alpha_2+\gamma_2P_1-C_2)}{2(\beta_1+\beta_2R^2)} \qquad (5)$$

where

$$R \equiv \frac{K-M_1}{M_2-K} \cdot \frac{M_2}{M_1}. \qquad (6)$$

The "mileage mix ratio" R depicts the relationship of the standard K to the mileages of two models, and can be used to evaluate the ease of compliance by particular manufacturers. Its definition is borrowed from the constraint function (2), which itself implies a fixed relationship between large and small car quantities:

$$Q_2^* = Q_1^*R \qquad (7)$$

This result permits interpretation of R as the number of small cars relative to large cars which a company must sell to meet the standard. Thus, whenever $R > 1$, compliance requires the sale of more than one small car per large car. This will occur, given M_1 and M_2, for any $K > 2/(\frac{1}{M_1} + \frac{1}{M_2})$.[4]

The actual magnitude of the quantity change induced by imposition of a CAFE constraint can be measured, for large cars, as

$$Q_1^0 - Q_1^* = \frac{R[(\alpha_1 + \gamma_1 P_2 - C_1)\beta_2 R - \beta_1(\alpha + \gamma_2 P_1 - C_2)]}{2\beta_1(\beta_1 + \beta_2 R^2)} \tag{8}$$

This expression is positive as long as the bracketed term in the numerator is positive; that is readily shown to reduce to the condition that the constraint binds. Thus fewer large cars are sold, and their price is higher, under the CAFE standards, and in amounts reflecting the relative stringency of the constraint. The same intuitive conclusion holds true in the reverse direction for small cars.

Although the four domestic auto manufacturers have many models of varying fuel economy, the force of these implications is evident by examining a single large-selling big car and a single large-selling small car from each of their recent product offerings. These are displayed in Table 1, along with various data for the last full model year.[5] As is apparent, GM's high mileage small car (M_2) gave it a desirable structure of vehicle offerings relative to the 1979 mileage standard K=19, as measured by its mileage mix ratio R. Sales of its low-mileage cars were

TABLE 1

1979 Models of Domestic Auto Manufacturers

	GM	Ford	Chrysler	AMC
Large Car				
Name	Impala/Caprice	LTD	Newport/St. Regis	Concord
Price[1]	$5600	$5900	$6100	$4200
Mileage (mpg)[2]	16	15	16	18
Sales (000)[3]	356	191	61	50
Small Car				
Name	Chevette	Pinto	Omni/Horizon	Spirit
Price[1]	$3800	$3600	$4100	$4000
Mileage (mpg)[4]	29	22	25	22
Sales (000)[3]	194	117	182	22
Mileage Mix Ratio R	.54	1.96	.78	.41
Two-Model Harmonic Ave.	19.0	17.1	21.9	19.1
Projected Overall Ave.	19.1	18.9	20.1	20.1

1 Beginning 1979 model year.

2 With automatic transmission and 8-cylinder engine, except for AMC where 6-cylinder was substituted on basis of actual sales volume.

3 1979 model year to April 30.

4 With manual transmission and 4-cylinder engine.

Sources: Mileages from EPA Fuel Economy Estimates, September 1978.
Sales from Wards Automotive, various issues.
Projected CAFE from April 6, 1979, NHTSA release.

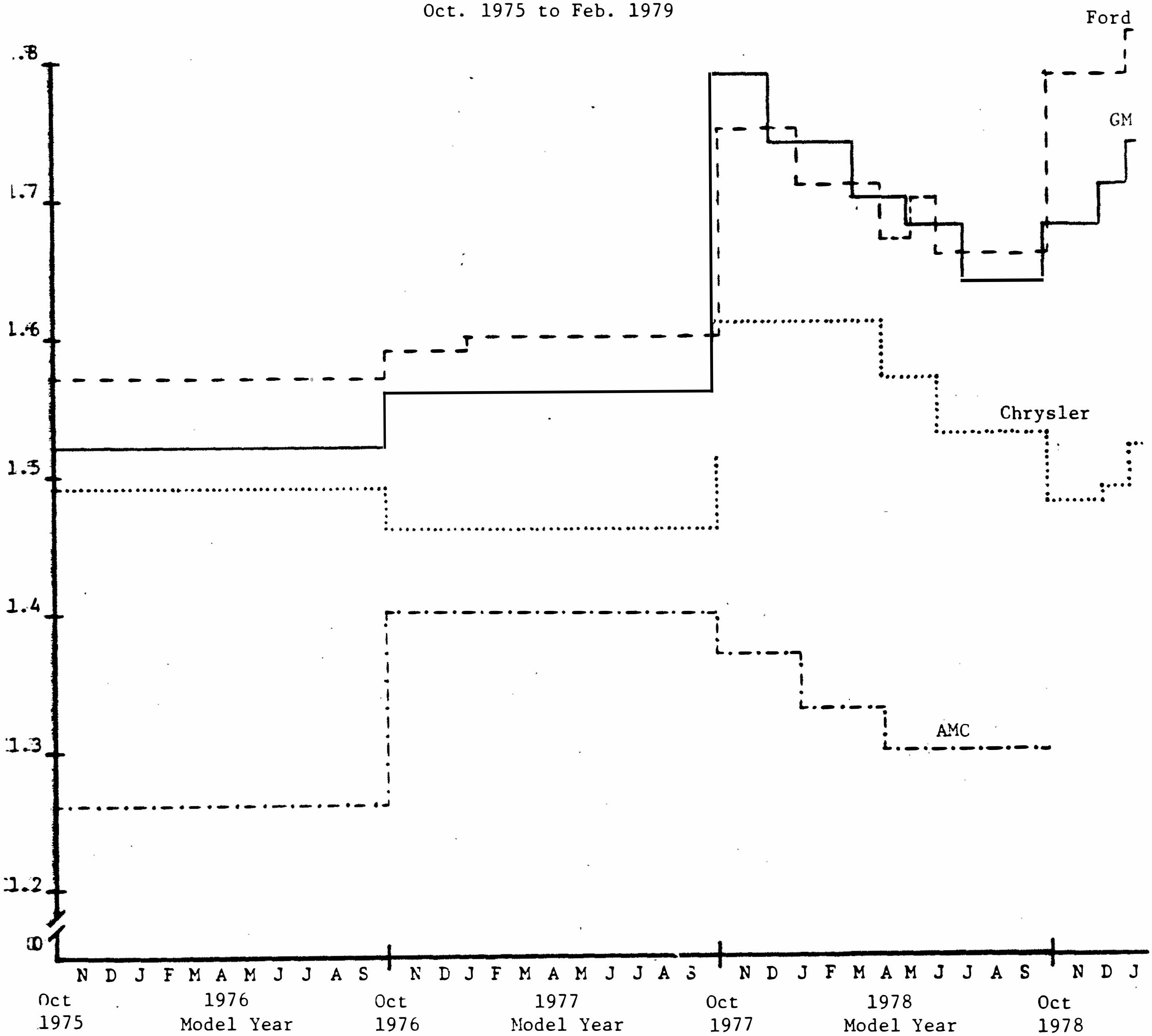
relatively heavy, however, causing its "two-model harmonic average" to decline almost to the standard itself. This figure is calculated as if these were the company's only two product offerings. The heuristic value of this number for each manufacturer is reflected in its broad consistency with projected CAFE for that model year (also in Table I).

Ford's product offerings reveal the source of some of its compliance problems. The considerably smaller mileage rating on its small car produced a value of R suggesting the need to sell much more than one such car for each large car. In addition, sales of its small car were erratic, periodically threatening its ability to meet CAFE and forcing it to raise prices on its bigger cars and to ration low-mileage optional engines.[6] These factors combined to produce, as of mid model year for Ford, both a two-model average and anticipated average below the standard. Chrysler's product offerings, while having not quite as high an M_2 as GM's, produced an R much closer to GM's than to Ford's. Weak sales on its larger low-mileage cars, however, magnified this effect and produced two-model and projected averages well in excess of the regulatory standard. Finally, AMC offered two good mileage vehicles, which suggested no great difficulties relative to the standard. Its actual vehicle sales mix generated relatively high average mileages for the company's model year.

The companies' use of pricing to shift mix is graphically illustrated in Figure 1. Each line depicts the relative price of the large and small cars identified in Table 1 over a three and a

FIGURE 1

Relative Prices, Large vs Small Cars, for Domestic Manufacturers*
Oct. 1975 to Feb. 1979



* The relative price line for each firm was calculated by dividing the price of the firm's "typical" large car by the price of its typical small car. The models used to calculate the relative price lines are as follows:

GM - Impala vs Chevette

Ford - LTD vs Pinto

Chrysler - Newport vs Volare (1976 and 1977 Model Years)
Newport vs Horizon (1978 and 1979 Model Years)

AMC - Matador vs 6 cyl Gremlin (Oct. 1975-Feb. 1977)
4 cyl Gremlin/Spirit (Feb. 1977-Feb. 1979)

half model year period. In 1976 and 1977, before the CAFE constraint, the ratio of large to small car prices was 1.5-1.6 for the three companies with true large cars. Most companies appear to have raised relative prices considerably with the beginning of the 1978 model year, presumably as one facet of their initial overall fuel economy strategies. During that year, small car prices rose as the result of increases in import prices (due in turn largely to the appreciation of the yen), producing the declines in relative prices shown. Yet the patterns differ significantly. GM's relative prices increased again, but not to their October, 1977 peak since its average fuel economy safely exceeded the standard. Ford was forced to raise its prices further in an effort to shift the mix of its vehicles sales, while Chrysler let its relative prices stay fairly low via further increases in the price of its fast-selling small cars. AMC, with a similar CAFE margin, kept its small car price up and large-to-small car relative price down.

This is, of course, exactly what would be expected based on the crude figures in Table 1, but there are three conclusions worth noting. First, the use of mix shift is not only a last resort, though it surely is that as well. Some mix shift has been part of each manufacturers' overall strategy since the advent of the CAFE constraint. Secondly, the CAFE requirement raises the possibility of different pricing behavior among the auto companies. Prices may now be used to serve other than single-vehicle profit objectives, and to the extent that these vary among companies, so will the prices. Finally, market efficiency losses are increased by the CAFE constraint insofar as prices are raised in low-elasticity markets and lowered in high elasticity markets. Both firm profits and consumer surplus are thereby reduced, though of course the standards were intended to serve nonefficiency objectives.

III. Fuel Savings

Mix shift has another, more subtle implication which deserves attention. NHTSA employs the CAFE standards in its procedures for estimating the fuel savings generated by the program. For future years, demand estimates are used to obtain figures on aggregate sales and the appropriate mileage standards are applied to its projected total miles driven each year. Consumption is compared to that which would have been occurred with the pre-CAFE 1977 fleet average of 17.6 miles per gallon. A number of concerns about this procedure are well known: the use of the 1977 benchmark ignores any subsequent responses to higher priced fuel;[7] the application of the standard to passenger cars may have contributed to a surge in sales of (low-mileage) light trucks and vans, as consumers shifted toward vehicles which still embodied desired attributes; and consumers may simply postpone purchase if the functional attributes of new products are judged unattractive.

But another possible source of bias in the fuel savings estimates has not been explored. The mix shift which CAFE induces will in general change the total number of cars sold in any year (from its predicted value) and hence make CAFE an inaccurate measure of consumption relative to some benchmark. Total consumption must therefore take into account both CAFE and induced changes in unit sales. Specifically, when the constraint binds, large and small cars become "tied" goods to the manufacturer, because only by selling high-mileage small cars can it sell low-mileage profitable cars. Under certain circumstances (see equation (7)), the sale of each additional big car may require more than one small car to be sold. Then the constraint may cause total sales to rise as companies optimally shift their mix, and average mileage per vehicle no longer reflects total fuel consumption.

Generally, the savings in total fuel consumption is given by

$$FS = L\left[\frac{Q_1^*}{M_1} + \frac{Q_2^*}{M_2}\right] - L\left[\frac{Q_1^0}{M_1} + \frac{Q_2^0}{M_2}\right] \tag{9}$$

where L is the constant number of miles driven per car per year. The simplistic estimating procedure just described assumes post-constraint total fuel consumption to be

$$L\left[\frac{Q_1^*}{M_1} + \frac{Q_2^*}{M_2}\right] = \frac{H^0}{H^*} L \left[\frac{Q_1^0}{M_1} + \frac{Q_2^0}{M_2}\right] \tag{10a}$$

where H^0 and H^* denote the harmonic averages of the mileages of actual sales before and after the constraint ($H^* \equiv K$). Substituting definitions of H^0 and H^* yields the following equivalent expression:

$$\frac{Q_1^*}{M_1} + \frac{Q_2^*}{M_2} = \frac{Q_1^0+Q_2^0}{Q_1^*+Q_2^*} \cdot \left[\frac{Q_1^*}{M_1} + \frac{Q_2^*}{M_2}\right] \quad (10b)$$

Clearly this method accurately measures fuel consumption if and only if $Q_1^0 + Q_2^0 = Q_1^* + Q_2^*$, i.e., total sales are constant. Total sales, however, can either rise or fall under mix shift, and under conditions which can be determined.

Consider first some plausible circumstances under which total sales rise and thereby offset at least partially the fuel savings estimated by the simplistic technique. The necessary and sufficient condition for such a partial fuel consumption offset is that[8]

$$Q_2^* - Q_2^0 > Q_1^0 - Q_1^* \quad (11a)$$

From (8) and an equivalent expression for small cars, this becomes

$$\frac{(\alpha_1 + \gamma_1 P_2 - C_1)\beta_2 R - (\alpha_2 + \gamma_2 P_1 - C_2)\beta_1}{2\beta_2(\beta_1 + \beta_2 R^2)} > \frac{R[(\alpha_1 + \gamma_1 P_2 - C_1)\beta_2 R - (\alpha_2 + \gamma_2 P_1 - C_2)\beta_1]}{2\beta_1(\beta_1 + \beta_2 R^2)} \quad (11b)$$

or $\quad \dfrac{\beta_1}{\beta_2} > R. \quad (11c)$

This condition implies that a given required vehicle mix is more likely to involve larger total sales when the slope of the inverse demand function is smaller (i.e., quantity responsiveness to price is greater) on the vehicles whose sales must be increased relative to the other vehicle. That is, while the equilibrium point entails fixed proportionate quantities, the absolute magnitude will be greater whenever the optimum pricing strategy requires lowering price in relatively price-sensitive markets and raising them in relatively insensitive markets.

Since the slope of demand for small cars (whose numbers must be increased) is shallow relative to that of large cars, this condition can be readily satisfied in the CAFE-constrained automobile market. A plausible numerical example will illustrate this and other previously discussed effects. Assume the following demand conditions:

$$P_1 = 9000 - Q_1 + .50\ P_2 \qquad (12a)$$

$$P_2 = 2500 - .50\ Q_2 + .50\ P_1 \qquad (12b)$$

Assume further that the marginal cost of each large car is \$5000, and each small car, \$3500, and that their respective mileages are 15 and 25. The unconstrained profit-maximizing point is given by P_1^0=\$8266, Q_1^0=3267; P_2^0=\$5067, Q_2^0=3132.[9] Total quantity is 6399 units, with an average mileage of 18.6. Now if a 20 mpg constraint is imposed, it obviously binds and gives the following solution values: P_1^*=\$8854, Q_1^*=2548; P_2^*=\$4804, Q_2^*=4246. Total quantity has risen to 6794 units. The initial total fuel consumption (calculated at 10,000 miles per car) was 3,431,000, and under the constraint, 3,397,000. While the latter is less, it is considerably different from the 3,191,000 figure obtained under the constant quantity assumption of equation (9a), which multiplies initial consumption by a fraction reflecting the average mileage gain, $\frac{18.6}{20.0}$. Indeed, in this example, only about 14 percent of the simplistically calculated gain is actually realized.[10]

Other properties of this model are noteworthy. Relative prices (P_1/P_2) have risen from 1.63 to 1.84, much like those described in Figure 1. The profit accruing to the seller (actually, the gross variable margin, since fixed costs have been ignored) have declined from $15,578,000 to $15,357,000. Simultaneously, the higher price in the less elastic large car market has increased deadweight loss there, only partially offset by the lower deadweight loss in the high elasticity, small car market. The change in one market is represented by the shaded area in Figure 2, and can be expressed for both markets as

$$\Delta DW = (Q_1 - Q_1^*)\left(\frac{P_1^0 + P_1^*}{2} - C_1\right) + (Q_2^0 - Q_2^*)\left(\frac{P_2^0 + P_2^*}{2} - C_2\right) \qquad (13)$$

Actual calculation reveals an increase in deadweight loss in the amount $956,000. This exceeds the decline in firm profits of $221,000, the remainder derived from a decline in consumer surplus.

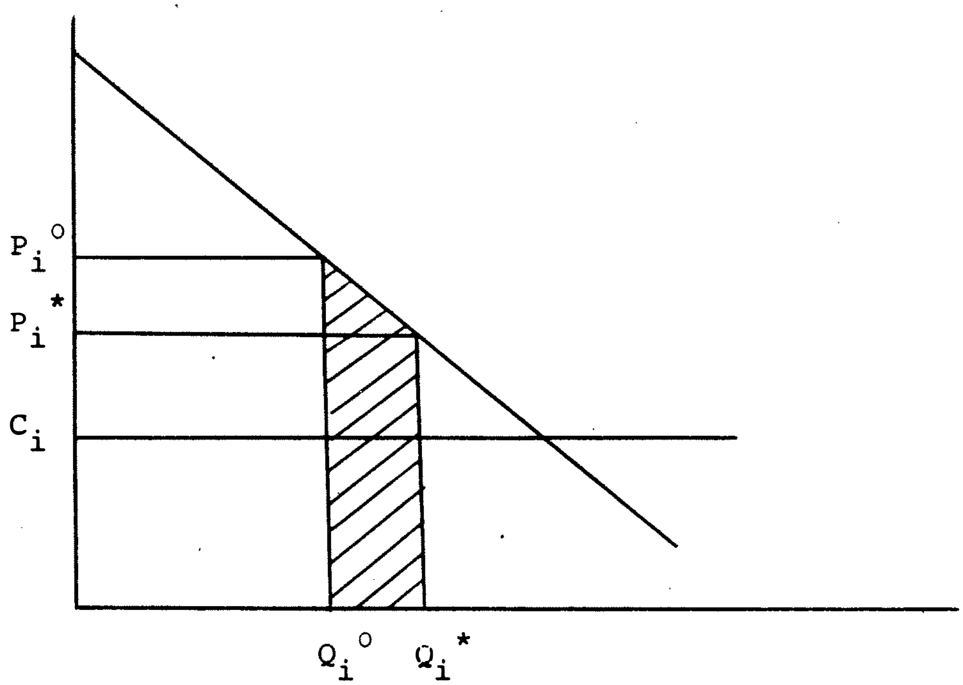
Consider finally the extreme case of a sufficient increase in sales to <u>fully</u> offset the higher average mileage and actually increase total fuel consumption. From (9) it is evident that this possibility requires only that

$$\frac{Q_2^* - Q_2^0}{M_2} > \frac{Q_1^0 - Q_1^*}{M_1} \qquad (14a)$$

which is equivalent to

FIGURE 2

Change in Deadweight Loss,
One of Two CAFE-Related Auto Markets



$$\frac{\beta_1}{\beta_2} > R\,\frac{M2}{M_1} \tag{14b}$$

While this is a more stringent condition than (11c), since β_1/β_2 needs to be M_2/M_1 greater than before, it continues to be entirely feasible and consistent with other known properties of the model. In practice, the phenomenon may not be very likely to extend to this point, but this demonstration further highlights the inaccuracy of assuming literally no mix shift offset in calculating aggregate fuel saving.

IV. Conclusions

Regulation can be and needs to be modeled as an additional constraint or a change in an exogenous variable in the environment of a firm. Only in this manner can the larger consequences be captured, and without doing so, potentially serious oversights are possible. In the present case, the fuel economy constraint on auto manufacturers has been shown to alter their behavior in ways that change relative prices depending on the mileages of each manufacturer's cars, increase deadweight losses in the market, alter the total quantity of vehicles, and perhaps thereby offset at least partially the fuel saving envisioned. These effects were not contemplated in the original design of the CAFE device, but they are important considerations in a full evaluation of its costs and benefits.

FOOTNOTES

1 See "Passenger Automobile Average Fuel Economy Standards: Final Rule," Federal Register, Vol. 42, No. 126 (June 30, 1977), pp. 33537-44; "Automotive Fuel Economy Program: Third Annual Report to the Congress," NHTSA, January 1979, pp. 42-55.

2 "Final Rule," p. 33535; "Report to Congress," p. 44.

3 The harmonic, rather than the arithmetic, average is appropriate under the assumption that all cars drive the same number of miles. Then the total miles driven by a manufacturer's cars, each of which goes L miles per year, is given by $LQ_1 + LQ_2$, and total gallons consumed is $\frac{L}{M_1} Q_1 + \frac{L}{M_2} Q_2$. Dividing gives the harmonic average

$$\frac{Q_1 + Q_2}{\frac{Q_1}{M_1} + \frac{Q_2}{M_2}}$$

4 Note that R therefore exceeds unity for K equal to the arithmetic mean of the mileages. The harmonic mean is always less than the arithmetic.

5 The choice criteria were car specifications (wheelbase, etc.), price, and sales. The latter are relatively fewer for Chrysler's and AMC's "large" cars, but the models listed are nonetheless appropriate. It should be noted that AMC's Concord, while its largest vehicle, is considerably smaller and less expensive than the true large cars of the Big 3 manufacturers. Its larger model, the Matador, ceased production with the 1979 model year. Sales figures extend up through early Spring, 1979, when huge demand shifts, due to concern over gasoline availability, began to take place. Subsequent to that time, the CAFE constraint has become, at least temporarily, nonbinding.

6 Its Pinto sales problems resulted in part from the adverse publicity concerning gas tank fires. See, for example, "Ford Curbs Sales of Big Engines in 1979 Vehicles," Wall Street Journal, November 9, 1978, p. 3.

7 This is acknowledged in "Report to Congress," p. 26.

8 Since savings are calculated for the entire domestic fleet and not for individual manufacturers, this discussion is best interpreted as the former.

[9] This implies, for example, demand elasticites of 2.5 for large cars and 3.25 for small cars, within the bounds of estimated elasticities for such categories of vehicles.

[10] This example remains partial inasmuch as it assumes (as does NHTSA) that all cars travel the same number of miles per year and that the increase in total units represents a net addition to the stock of vehicles on the road. The latter would be true as long as purchase of the increment (low-priced small cars) are previous nonowners of cars or buyers of second cars, or if such purchase by previous car owners releases more vehicles to the secondhand market, lowering price and inducing greater quantity demanded at the margin. (For a similar argument with respect to the equilibrium stock effects of style change, see F. M. Scherer, Industrial Market Structure and Economic Performance, (Chicago: Rand McNally, 1980) p. 400.) If, however, scrappage of old low-mileage vehicles increases as the result of a larger flow of high-mileage new cars into the market, additional fuel savings are possible from the entire vehicle fleet. The partial effect demonstrated in this exercise, however, would still operate.