Advances in Automobile Technology and the Market for Fuel Efficiency, 1978–1985

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The Corporate Average Fuel Economy standards for automobiles and light trucks were intended to improve energy efficiency primarily through technological improvements. While it is not clear how much of the impetus for manufacturers to improve fuel economy should be attributed to the Corporate Average Fuel Economy, analysis of light-duty vehicle sales and characteristics since the Corporate Average Fuel Economy went into effect in 1978 does indicate that technological improvements are responsible for about one-half of the 40 percent increase in automobile fuel economy between 1978 and 1985. Size class shifts are responsible for only 10 percent of the total gain. The 1978–1985 market for automotive efficiency reflects interactions of demand shifts, regulation, and technological change. An attempt is made to measure the technical improvements in automotive fuel efficiency by estimating stochastic frontier cost functions for automotive fuel economy in 1978 and 1985.

The Corporate Average Fuel Economy (CAFE) standards for automobiles and light trucks (Energy Policy and Conservation Act of 1975) were based on the assumption that cost-effective technology for nearly doubling automotive fuel economy without significantly affecting consumer satisfaction existed, and should be used. This assumption is reflected in the fact that when National Highway Transportation and Safety Administration (NHTSA) established the fuel economy standards in its final rule, it assumed that no sales shifts would be required to reach 27.5 mpg in 1985 *(1)*. Some critics of the standards have assumed that technology would not advance and that the standards would have to be met by forcing producers and consumers to settle for less desirable combinations of fuel efficiency and other attributes *(2–4)*. Examined in this paper are the trends in automobile sales and characteristics from the first year of the CAFE standards to the present (1978–1986). The purpose of this paper is to contribute to the theoretical and factual bases for consideration of the appropriateness of the standards as currently formulated. This review indicates that technological improvements, rather than merely a move to smaller or less desirable but more efficient vehicle designs, have been a major factor in the 40 percent increase in automotive efficiency since 1978. Trends in market demand have also been important, however, and there is also evidence that the range of choices available to consumers has been reduced. A reconsideration of CAFE standards should begin with an understanding of the interdependence of these factors and the role that they have played in past mpg improvements.

First, a brief discussion of the economics of the market for vehicle attributes is required to provide a context for the facts and figures. This discussion is followed by an exploration of the changes in vehicle characteristics (weight, engine size, vehicle size) that are directly or indirectly important to consumers, that most directly affect mpg, and whose effect is mediated by the technology that manufacturers incorporate in the vehicles they produce. (Throughout this paper, technology is used in the economist's sense to represent the production capabilities of firms. An advance in technology therefore does not necessarily imply an advance in scientific or engineering knowledge but could instead result from the application of existing knowledge.) Stochastic frontier production functions that quantify technological change are estimated. Finally, changes in light-duty vehicle fuel economy from 1978–1986 are decomposed into a variety of sales shift and vehicle engineering categories. The categories do not correspond exactly to the technology versus demand shifts dichotomy that is desired but do help to understand the relative magnitudes of these components.

ECONOMICS OF VEHICLE ATTRIBUTES

It is useful to consider the automobile market to be a market for vehicle characteristics rather than for uniform vehicle units. This characterization of the market for attributes of commodities is referred to in the economics literature as "hedonic demand analysis" *(5–7)*. Each vehicle is a bundle of characteristics that includes fuel efficiency, carrying capacity, luxury, and other numerous and often vague attributes. It is assumed that consumers possess "bid functions" that express their willingness to pay for each attribute at given levels of all others. A consumer's bid function for the ith attribute, B_i, depends on the prices of all attributes, p, and other characteristics of the consumer, c (e.g., his income, age, tastes). Producers, on the other hand, possess "offer functions," O_i, which express their ability to supply attributes given the prices of all inputs to production, w, the technology available to them, T, and regulatory constraints, R. The market can be described by sets of different bid functions for different consumers (j) and offer functions for producers (k).

$$O_{ik}(w, T, R) = B_{ij}(p, C) \qquad (1)$$

The reason it is so difficult to ascribe changes observed in the market to any particular cause is that these functions are

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numerous and interdependent. Bid functions generally are unobservable. Only the intersections of bid and offer functions can be observed. Intersection points (actual vehicle characteristics bundles) may shift when consumers' bid functions shift in response to higher fuel prices, demographic changes, or changes in tastes. Figure 1 shows the trade-off between vehicle weight and fuel efficiency in gallons per mile. Higher fuel prices cause the bid function (demand curve) to shift downward, resulting in lighter, more efficient cars. Attribute bundles offered may shift in response to higher factor prices, regulation, or technological change, which cause producers' offer functions to shift. The same shift caused by higher fuel prices could be achieved via regulation by restricting the supply curve to the dashed portion. This forces consumers to accept something other than their preferred attribute bundle, resulting in a loss in economic efficiency. An improvement in technology is shown in Figure 1 by a shift in the offer function (supply curve) to the left. Without any change in demand, this results in heavier and more efficient cars. Shifts in both supply and demand could result in both lighter and more efficient cars.

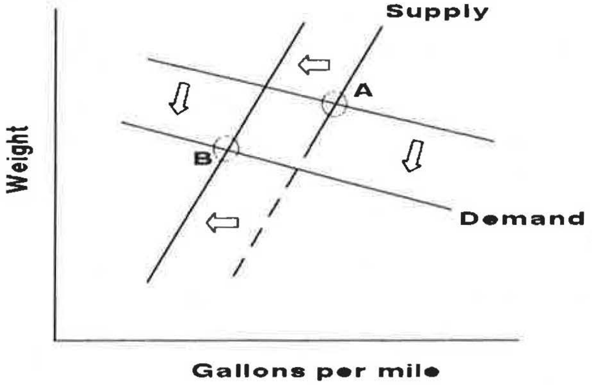

FIGURE 1 Trade-off between vehicle weight and fuel efficiency in gallons per mile.

Regulation, such as CAFE, is an attempt to alter the course of change. If it can be assumed that the market is functioning as a classical competitive market and technology is held constant (or assumed to respond correctly to market signals), then regulatory intervention can be justified only if it promotes a noneconomic societal goal (e.g., national defense). If the market is operating properly, consumers are getting the bundles of attributes they want most for the lowest possible price. Regulations that force producers to offer more fuel economy, either at a higher price or with less of some other desired attribute, also force consumers to accept vehicles with less of some other desirable attributes. Economic analyses of CAFE that have begun from these premises have inevitably concluded that the regulation would be *(2, 3)* or has been *(4)* harmful to the economy. However, the intent of CAFE was to stimulate or accelerate technological improvement, not to force consumers to accept vehicles with less desirable attributes. To shed light on this issue, the role of technological change in the market for fuel efficiency must first be understood. The technology of production can be viewed as a production function describing the quantity of output that can be produced for given levels of inputs. In this case, the outputs and inputs are multidimensional. The production function translates a vector of inputs, x_j ($j = 1$ to n), into a vector of vehicle attributes, y_i ($i = 1$ to m),

$$y = F(x) \tag{2}$$

For the cost-minimizing firm, there exists a cost function, C, for every production function, which gives the minimum cost, c, for producing a given level of output and given input prices *(8)*,

$$c = C(y, w) \tag{3}$$

Assume that one of the y_i's (let it be y_1) is fuel economy and that it is a function of some subset of the remaining y_i's, which is assumed to be $(y_2, y_3, \ldots, y_k)$. By the implicit function theorem *(8)* y_1 can be expressed as a function of y_2 through y_k.

$$c = C[y_1(y_2, \ldots, y_k), y_2, \ldots, y_m] \tag{4}$$

The importance of this is that fuel economy can be expressed as a function of other vehicle attributes, and this function will represent the state of technology for producing fuel economy at a given time. This result can be used to construct production frontiers for 1978 and 1985 and determine whether or not the frontier (technology of production) has advanced.

CHANGING ATTRIBUTES AND THE TECHNOLOGY FRONTIER

Many attributes may be indirectly related to fuel economy. From an engineering point of view, however, there are only a few attributes that have both a major influence on fuel economy (an influence large enough to have contributed significantly to the more than 40 percent increase in automobile fuel economy from 1978 to 1986) and important implications for consumer satisfaction. The attributes used here are vehicle weight, engine size (or size to weight ratio), projected frontal area (width times height), and price. An attribute such as interior space may be assumed to influence fuel economy, but its influence may be entirely a function of its effect on weight, engine size, and frontal area. Thus, if the latter three variables are included in the implicit function for fuel economy, interior space need not be included. To be sure, numerous other factors affect fuel economy, for example, internal engine friction, but these factors are unimportant to consumer satisfaction.

From the viewpoint of this analysis, reduction of internal engine friction represents a technological improvement. In the discussion that follows, assume that fuel efficiency can be expressed as a function of curb weight, engine displacement divided by curb weight, projected frontal area (width times height), and a measure of luxury accessories.

If each automobile sold in any year was represented by a point in a six-dimensional (weight, power, frontal area, fuel economy, price, luxury) space, the envelope or outer surface of that space would represent the technology frontier—the highest level of fuel economy achievable for a given weight, power, area, and cost, given the input prices and technology of that year. An improvement in technology is then defined as a movement of the frontier toward better fuel efficiency, other things equal.

The data for the analyses that follow come from the "Oak Ridge National Laboratory MPG and Market Share Data System" *(9, 10)*, which contains sales statistics at the nameplate level (e.g., Chevrolet Cavalier) and shares of production by engine and transmission type, together with Environmental Protection Agency (EPA) estimated fuel economies and selected vehicle specifications.

Changes in the technology frontier from 1978 to 1986 are illustrated in two-dimensional plots of each attribute versus efficiency (Figures 2 through 5, prices are list prices in 1985 dollars). Not only has the technology frontier advanced, but points have also shifted relative to the frontier. Whereas in 1978 the best 2,500 lb automobiles achieved 25 mpg (0.04 gal/mi), the best in 1985 were getting 33 mpg (0.03 gal/mi). On the other hand, automobiles weighing more than 4,000 lb were virtually eliminated, which suggests a restriction of choice. In comparison with 1978, automobiles in 1985 are clustered closer to the frontier, suggesting that models have generally moved closer to the state of the art. The technology frontier for projected frontal area shows a similar advance (Figure 3), suggesting significant improvements in aerodynamic design.

Displacement to weight evidences no outward migration of points (Figure 4). There is a tendency for points to cluster closer to the frontier and a pronounced elimination of the highest engine size-to-weight ratios. A more direct measure of power (i.e., horsepower) would have shown different results, but such data were not available in the ORNL data base *(9)*. From 1978 to 1986, average horsepower per liter increased from 28.0 to 40.3 for domestic automobiles and from 46.0 to 56.5 for imports, according to *Automotive Industries* magazine *(11)*. This conclusion is supported by a linear regression of horsepower against engine displacement (cu in.) for domestic versus imported cars for 1978 versus 1985 using specifications published in *Automotive News'* annual edition. Turbocharged and diesel engines were excluded. The results (Table 1) indicate that a typical 150 cubic inch displacement (cid) domestic automobile would have 78.7 hp in 1978 but 100.0 hp in 1985. A 100 cid import would have 76.4 hp in 1978 and 82.0 hp in 1985. Thus no movement of the cid/weight frontier implies considerable improvement in the hp/weight frontier.

These snapshots of the technology frontier indicate advances on all four fronts. There is evidence, however, that the range of choices has been reduced. The heaviest automobiles and largest engine size-to-weight ratios of 1978 have disappeared. It also appears that on all fronts, points have moved closer to the frontier. This should reflect improved efficiency of production; that is, everyone is now closer to the state of the art.

STOCHASTIC FRONTIER COST FUNCTIONS

Although two-dimensional snapshots of the technology frontier are useful for illustration, they are inconclusive and possibly misleading because they fail to account for trade-offs among more than two attributes. What appears to be an advance in the gallons-per-mile versus frontal area frontier could actually be a reflection of the fact that automobiles with the same frontal area were lighter in 1985. To capture such effects, the cost function must be observed in all five dimensions.

Econometric techniques have recently been developed for estimating such technology frontiers by using models in which the error term is a convolution of truncated and untruncated normal distributions *(12)*. Recall that the cost function can be expressed with gallons per mile (gpm) as the dependent variable being a function of other vehicle attributes (a vector Y),

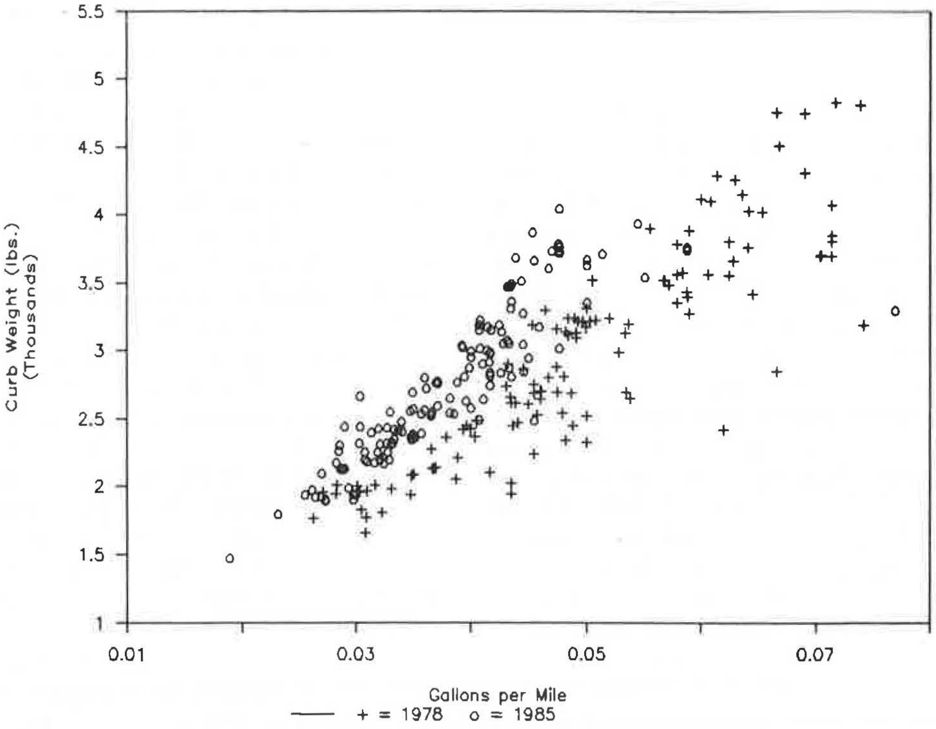

FIGURE 2 Weight versus efficiency, 1978 and 1985 automobiles.

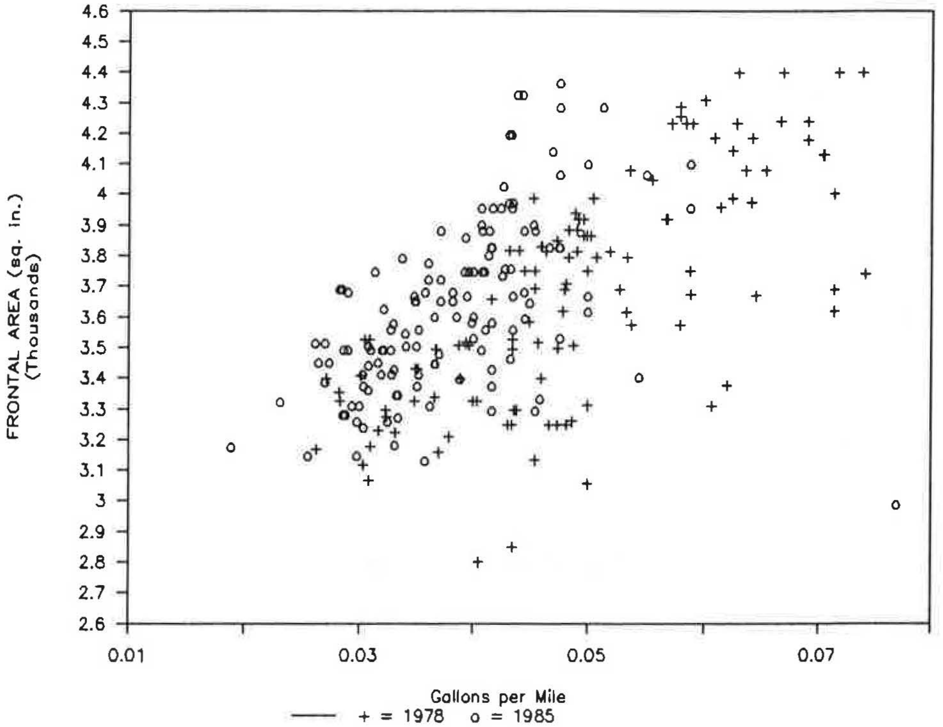

FIGURE 3 Frontal area versus efficiency, 1978 and 1985 automobiles.

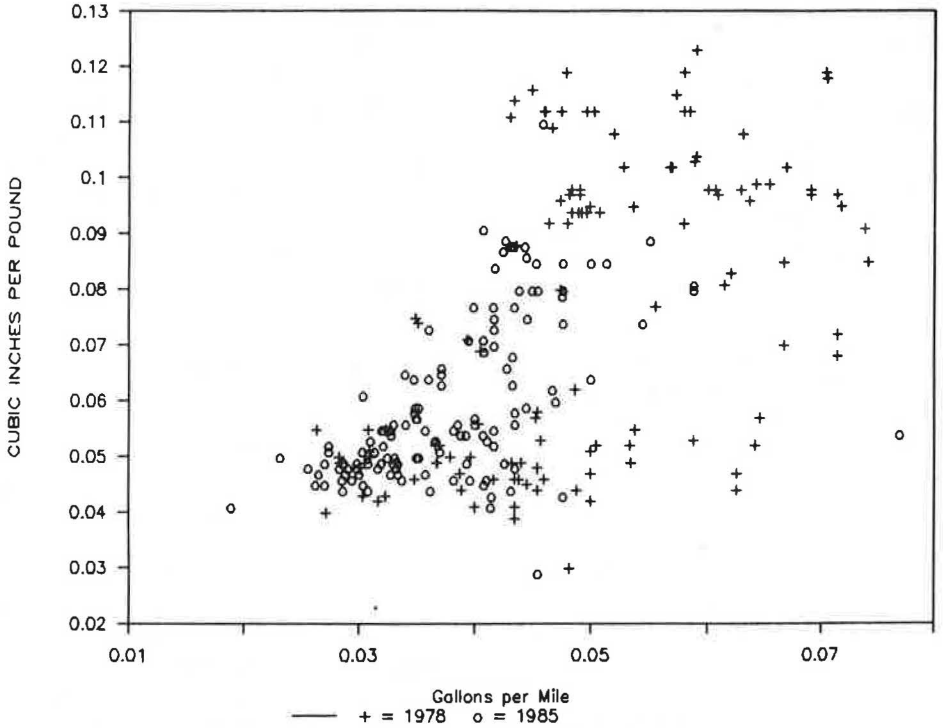

FIGURE 4 Displacement/weight versus efficiency, 1978 and 1985 automobiles.

and a vector of parameters to be estimated, which is indicated by b,

$$gpm = f(y, b) + \varepsilon \tag{5}$$

The usual assumption made in regression analysis is that ε is normal with mean = 0 and variance σ^2. The stochastic frontier model proposed by Aigner et al. *(13)* decomposes ε into two components,

$$\varepsilon = u + v \tag{6}$$

where u has the usual normal distribution and v is a half-normal distribution ($v >= 0$).

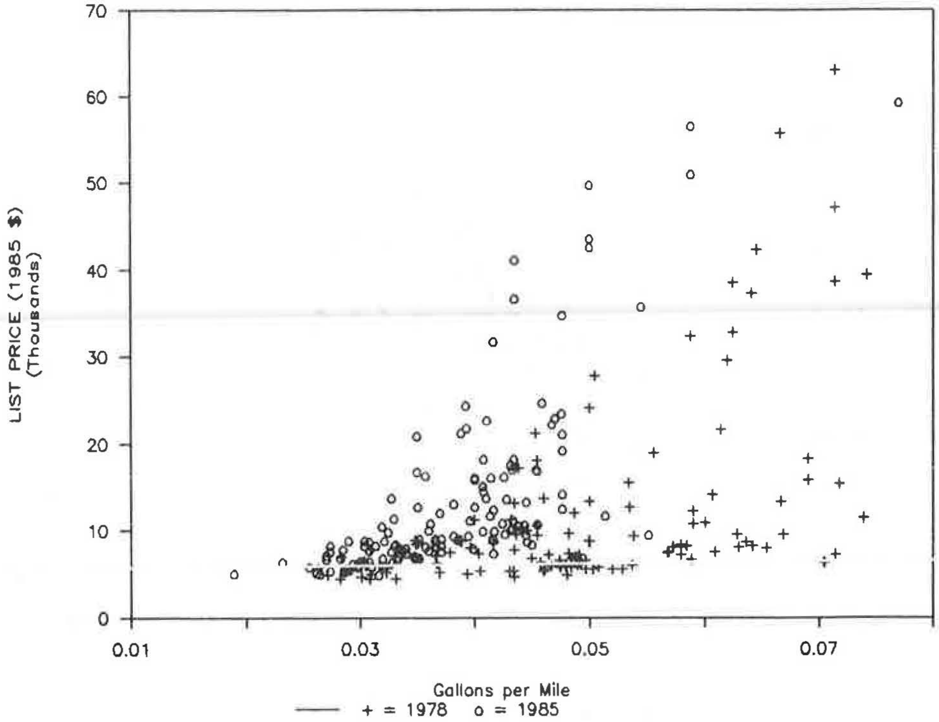

FIGURE 5 List price versus efficiency, 1978 and 1985 automobiles.

TABLE 1 LINEAR REGRESSION OF HORSEPOWER ON DISPLACEMENT

	Intercept	Slope	R^2
Domestic automobiles			
1978	19.52	0.3946	0.89
1985	43.89	0.3741	0.74
Imported automobiles			
1978	7.05	0.6929	0.95
1985	7.41	0.7457	0.91

NOTE: Measured in cubic inches.

The one-sided error term v is interpreted as deviations from the production frontier due to inefficiencies. Because the frontier represents the best technology, all points should lie on or above it (inefficiencies will result in greater than optimal gpm). The u term represents the usual random factors (e.g., measurement error, unobserved variables). Aigner et al. suggest using σ_v/σ_u as a measure of average inefficiency, because it expresses the deviations from the frontier due to inefficiency relative to those due to unobserved factors. The same authors note, however, that the separation of the residual variance into its two components cannot generally be satisfactorily accomplished, even for sample sizes as large as 100. Likewise, the estimates of σ_u and σ_v were found to be very sensitive to a few extreme data points. Gallons-per-mile frontiers were estimated with the 1978 and 1985 data illustrated earlier, using the LIMDEP *(14)* econometric software package. Figures 1–5 suggest that a simple linear frontier function will describe the data adequately. Four variables remained in the final equations, in addition to an intercept: (a) curb weight, in pounds; (b) price, in 1985 dollars; (c) engine size (in cubic inches) to weight ratio, a measure of performance; and (d) price to interior volume (in cubic feet) ratio, a measure of luxury. Frontal area was tested and found to be not statistically significant. The final parameter estimates are given in Table 2.

The pattern of signs on coefficients in Table 2 implies that fuel consumption will increase with increasing weight, power, and luxury. Thus, to obtain lower fuel use, consumers would have to give up some amount of each, if technology is constant. In contrast, fuel consumption decreases with increasing vehicle price; that is, for the same level of weight, power, and luxury, greater efficiency can be bought at a price. The trade-off rates can be computed by taking derivatives of each variable with respect to

$$dX/dmpg = (1/C_x)\ (mpg_t)^{-2} \tag{7}$$

where C_x is the estimated coefficient for the variable X and mpg is indexed by t to indicate that the trade-off rate is dependent on the level of mpg. Estimated average trade-off rates for 1978 and 1985, using the gpm predicted by the appropriate frontier function at the mean values of right-hand-side variables in the respective year, are given in Table 3. The mpg-weight trade-off rate is about the same in both years: 150 lb/mpg. The luxury trade-off rates are also close: about $35/ft^3 per mpg (1985 dollars). The dollar cost of mpg appears to have gone up considerably, however, $4,867 per mpg in 1985 versus $2,987 in 1978 (again, both are 1985 dollars). The power (engine size-to-weight ratio) cost of mpg appears to have decreased (0.0106 in.^{3}/lb/mpg in 1985 versus 0.0287 in 1978). This result is consistent with the increased level of horsepower available per cubic inch in 1985, as illustrated in Table 1.

The 1985 frontier is considerably lower than that of 1978, reflecting a significant advance in technology. To illustrate, two-dimensional graphs were drawn of the partial relationships between gpm and each variable, holding other variables constant at their 1978 average levels (Figures 6–9). In all cases, the

TABLE 2 STOCHASTIC GPM FRONTIER ESTIMATES

Variable	Coefficient	Std. error	Mean of var.	Elasticity
n=112		1978		
Intercept	1.338 E-04	2.430 E-03	1.0000	
Weight	1.291 E-05	8.212 E-07	3.036 E+03	7.867 E-01
Power	7.094 E-02	2.892 E-02	7.644 E-02	1.088 E-01
Price	-6.824 E-07	1.526 E-07	1.672 E+04	-2.289 E-01
Luxury	5.943 E-05	1.278 E-05	1.985 E+02	2.368 E-01
σ_v/σ_u	1.578 E 00	7.345 E-01		
$\sigma_v^2+\sigma_u^2$	6.863 E-03	1.031 E-03		
n=144		1985		
Intercept	3.217 E-03	2.011 E-03	1.0000	
Weight	8.260 E-06	7.743 E-06	2.794 E+03	4.632 E-01
Power	1.144 E-01	2.173 E-02	5.934 E-02	1.362 E-01
Price	-2.492 E-07	8.323 E-08	1.419 E+04	-7.098 E-02
Luxury	3.132 E-05	5.401 E-06	1.685 E+02	1.059 E-01
σ_v/σ_u	1.545 E-00	5.366 E-01		
$\sigma_v^2+\sigma_u^2$	5.116 E-03	5.179 E-04		

TABLE 3 ESTIMATED TRADE-OFF RATES BETWEEN MPG AND OTHER AUTOMOBILE CHARACTERISTICS

Characteristic	1978 Frontier	1985 Frontier
Weight (lb/mpg)	−157.8	−146.9
Price ($/mpg)	2986.9	4867.4
Power (cid/lb/mpg)	−0.0287	−0.0106
Luxury ($/ft^3/mpg)	−34.3	−38.7

1985 partial frontiers lie well below the 1978 partial frontiers. This means that the 1985 vehicles offer better fuel efficiency at the same price, weight, power, and luxury.

Although the frontier has advanced broadly, the slope of the frontier is generally less steep (the power versus gpm curve is the only exception, and the possible effect of the changing horsepower–engine size relationship has been noted previously). This means that while the technology of producing gpm has generally advanced, the ability to trade off vehicle attributes for improved fuel economy has become more difficult. In other words, the constant technology price of efficiency (reduced gpm) is higher in 1985.

These results show a definite improvement in the technology of automotive efficiency. In the following section, the size of this improvement is measured and compared with other attempts to break down automotive mpg gains into technological and other components.

EFFECTS OF SALES SHIFTS AND ENGINEERING CHANGES ON MPG

How do fuel economy improvements since CAFE break down into technological improvements, demand-induced sales shifts, and regulatory restriction of supply? So far, no one has been able to achieve such a breakdown. Attempts have been made to break down mpg changes into various components by means of engineering analysis or the analysis of sales and mpg data. Although these studies do not allow a clear distinction to be drawn between technological advances and regulation-induced restriction of choice, they do provide a substantial amount of information about how mpg improvements have come about, which may contribute to making informed judgments on this point. To these studies can now be added a decomposition into pure technological change (an advance of the frontier) versus all other factors, based on the 1978 and 1985 frontiers estimated earlier. Heavenrich et al. *(15)* grouped the estimated 77.8 percent mpg improvement of passenger automobiles from 1975 to 1985 into four categories: (a) powertrain optimization, (b) transmission type, (c) engine displacement and combustion type, and (d) vehicle weight (Table 4). For domestic and imported vehicles the majority of mpg improvement was allocated to powertrain optimization, which includes changes in engine design and calibration, emission control systems, transmission design details, axle ratio, and optimization with respect to the test procedure. Only domestic automobiles achieved significant mpg improvement by reducing weight. If it can be assumed that consumers are more or less neutral to powertrain optimization changes, then this analysis would allocate two-thirds or more of the 1975–1985 mpg gain to technological change (if costs were equal).

Another source of fuel economy changes broken down by engineering components is NHTSA's sixth annual report to Congress *(16)*. This report, the last by NHTSA to attempt such an analysis, allocates 4.35 mpg of the total 5.3 mpg change for passenger automobiles between 1978 and 1981. More than one-half of the total (2.35 mpg) was allocated to weight reduction, a sharp contrast to Heavenrich et al. estimates for 1975–1985. Aerodynamic drag improvements were allocated 0.37 mpg, lock-up torque converters 0.27 mpg, increased use of diesel engines 0.25, increased manual transmissions 0.14, increased use of five-speed manuals 0.09, and four-speed automatics and reductions in vehicle performance (hp/iw) 0.08 mpg. If weight and performance reductions or manual transmissions (diesels might arguably be omitted) are not counted, this leaves about 40 percent for technology improvements.

A method of decomposing year-to-year changes in mpg into sales shift and engineering design components was developed by Greene et al. *(17)*. By using sales figures and EPA combined

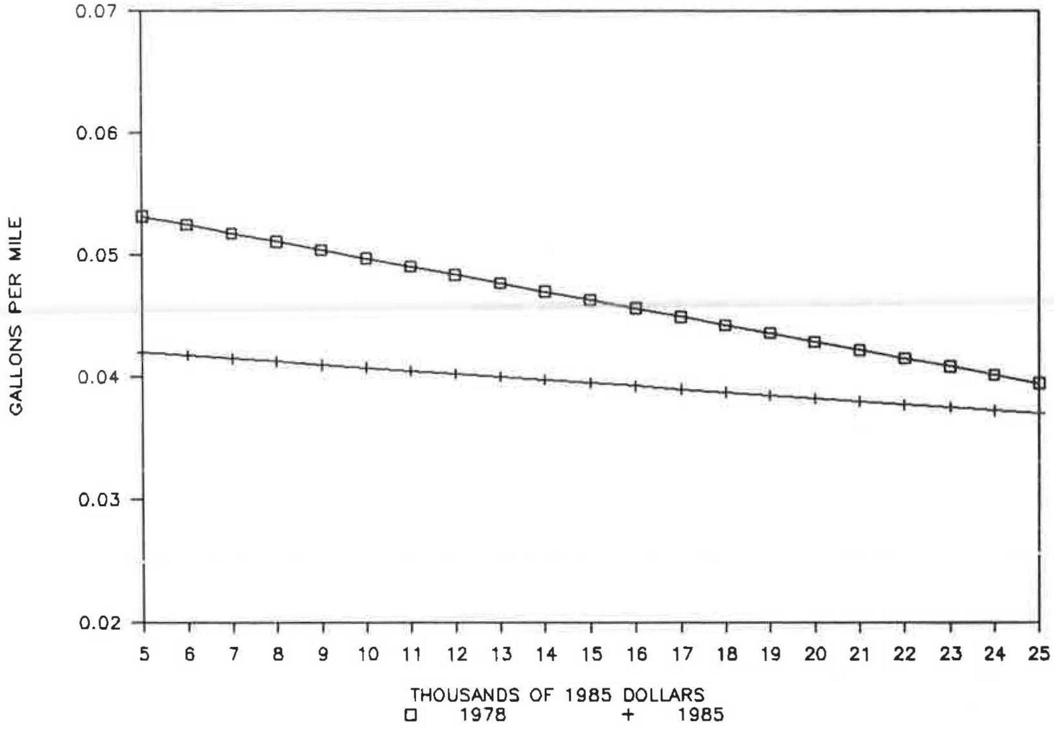

FIGURE 6 **Price versus efficiency frontiers, 1978 and 1985 automobiles.**

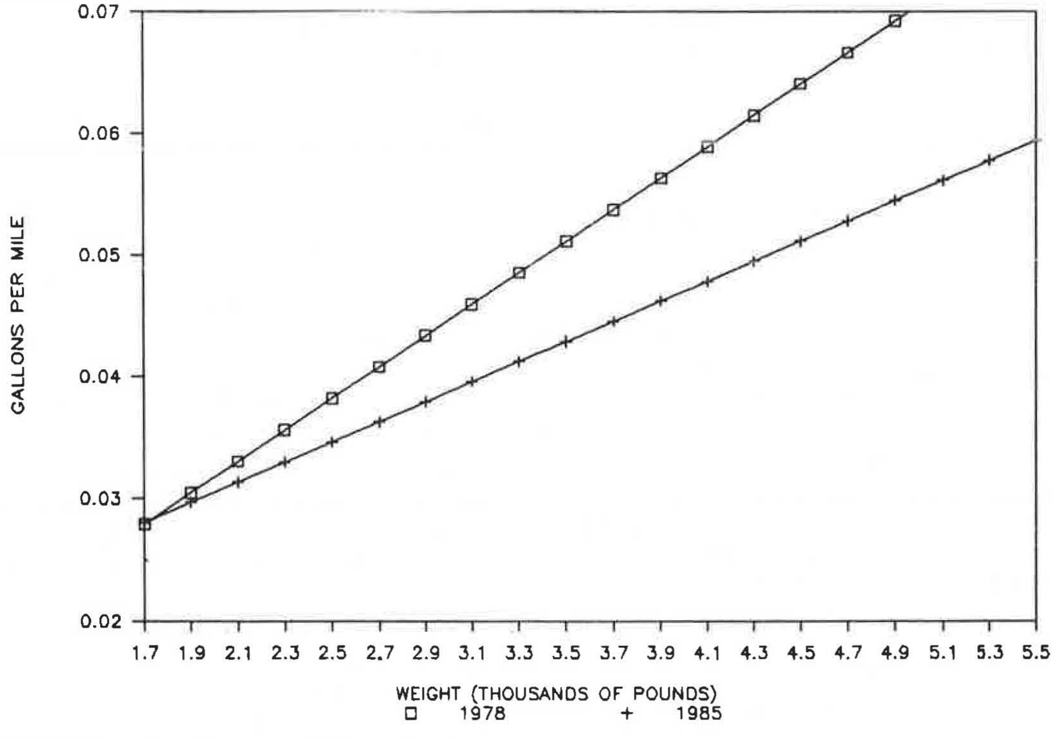

FIGURE 7 **Weight versus efficiency frontiers, 1978 and 1985 automobiles.**

city-highway fuel economy estimates, the method breaks out mpg changes into the following components:

1. Size class sales shifts,
2. Nameplate sales shifts,
3. Configuration sales shifts,
4. Continued configuration mpg improvements,
5. Nameplate introductions,
6. Configuration introductions,
7. Nameplate discontinuations, and
8. Configuration discontinuations.

The first three components capture sales shifts among makes, models, and configurations present in successive years.

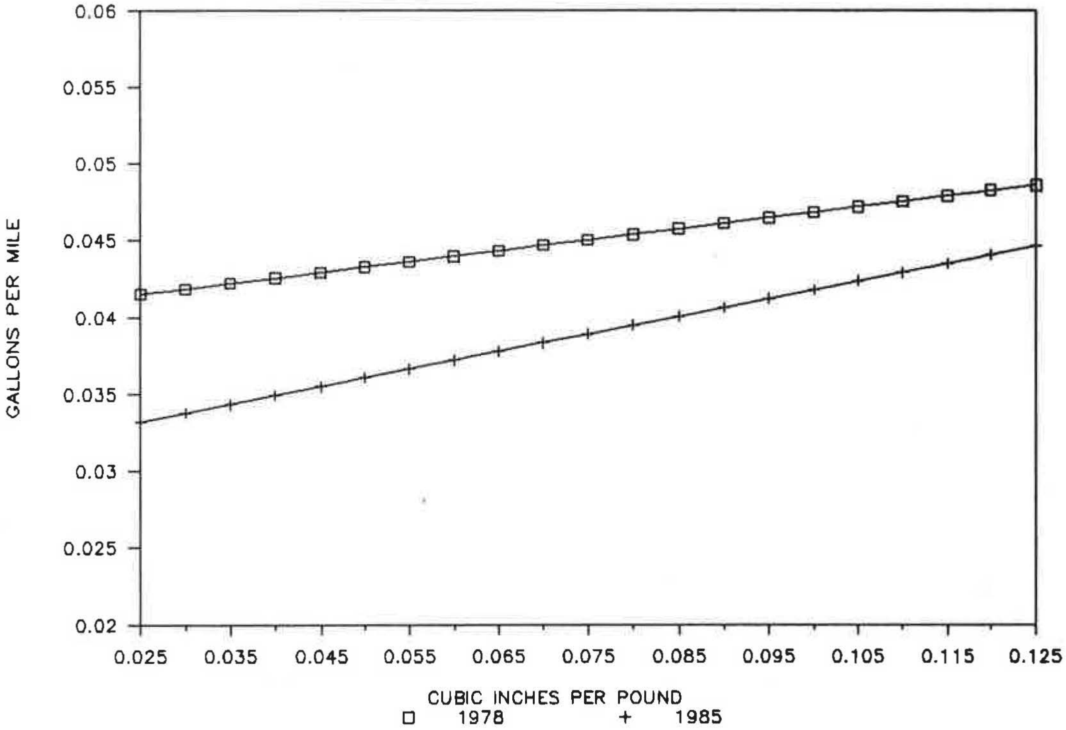

FIGURE 8 Engine displacement/weight versus gpm, 1978 versus 1985 automobiles.

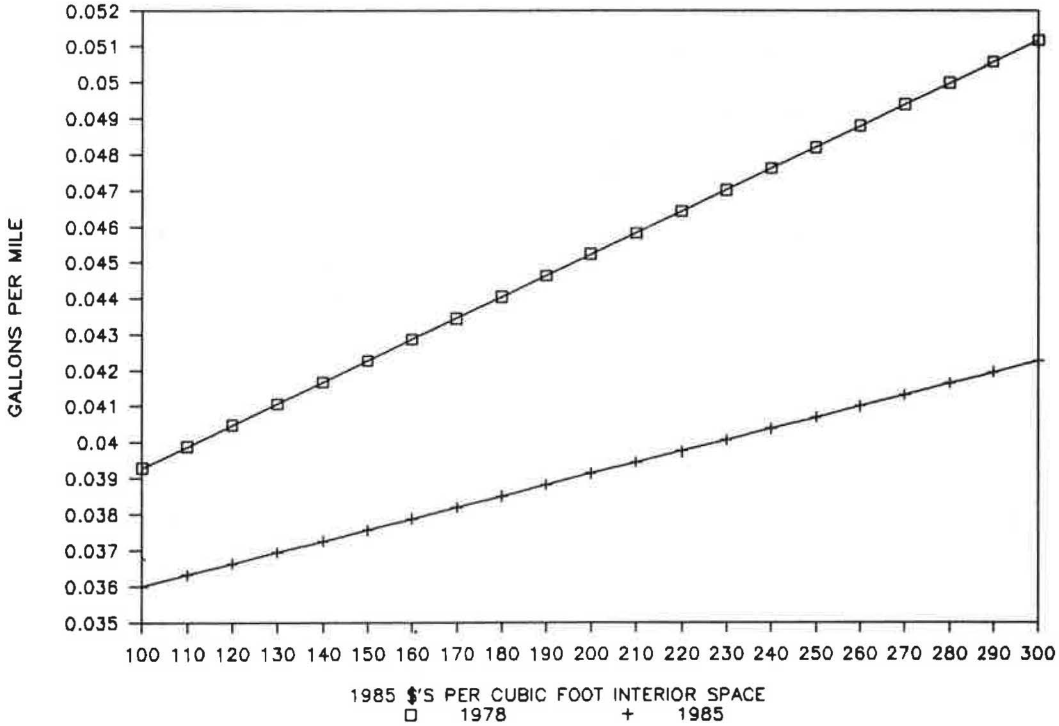

FIGURE 9 Luxury versus efficiency frontier, 1978 and 1985 automobiles.

Component 4 represents engineering and design changes that improve the efficiency of nameplate-engine-transmission combinations offered for sale in both years. If new nameplates or configurations are more efficient than the average for their class the previous year, this will show up as an introduction improvement (5 or 6). Discontinuation improvements are similarly defined.

The components of mpg changes from 1978 to the first 6 months of model year 1986 are given in Table 5. These calculations put to rest the popular notion that fuel-efficiency improvements have been achieved largely by consumers buying smaller automobiles, at least in terms of interior volume. Size class sales shifts account for 0.94 mpg over the 8-year period, only 11 percent of the total 8.35 mpg improvement. All sales shifts

TABLE 4 ALLOCATION OF MPG CHANGES FOR PASSENGER CARS, 1975–1985 (percent)

Mfg	1975 mpg	Power-Train	Trans-mission	Engine	Weight	1985 mpg
Domestic	14.7	41.8	–0.0	–0.5	26.1	26.2
European	23.0	24.8	–0.3	–1.8	–3.9	27.6
Japanese	23.5	39.7	–1.8	2.7	–2.4	32.3

TABLE 6 ANALYSIS OF 1978–1985 MPG IMPROVEMENT INTO TECHNOLOGICAL CHANGE AND CHANGES IN AUTOMOBILE CHARACTERISTICS

Frontier Function	Automobile Characteristics (year) 1978	1985
Gallons per Mile		
1978	0.0474	0.0399
1985	0.0412	0.0342
Miles per Gallon		
1978	21.0853	25.0645
1985	24.2641	29.2745

account for about 35 percent of the gain, while all engineering and design changes account for 65 percent.

The contribution of sales shifts is significant because if the engineering changes manufacturers were offering to consumers were considered less desirable, the effect of sales shifts would be expected to be negative, away from the more efficient nameplates and configurations and toward the less efficient (perhaps more powerful and heavier) ones. Consumer demand shifts in favor of higher fuel efficiency at the same time that improved fuel economy technology is introduced (movement from point A to B in Figure 1) are consistent with the assertion that consumer demand has shifted in favor of greater efficiency at the same time that technology has advanced.

The 1978 and 1985 technology frontiers provide a means of separating the effects on mpg of changed vehicle attributes (whether because of sales shifts or design changes) versus pure technological improvement (Table 6). This is done by making four mpg predictions with all four combinations of the 1978 and 1985 frontiers and the 1978 and 1985 average automobile characteristics (the averages used here, unlike those discussed previously, are sales-weighted averages of all automobiles in the respective years). For example, the average 1978 automobile has a predicted fuel economy of 0.0474 gpm or 21.1 mpg when the 1978 frontier function is used (recall that the frontier is the best technology and that nearly all automobiles will not do that well). An automobile with the same attributes produced in 1985 would have a fuel efficiency of 0.0412 or 24.3 mpg, according to the 1985 frontier function. Similarly, an automobile with average 1985 attributes produced in 1978 would have a predicted efficiency of 25.1 mpg, but if produced in 1985 would have a predicted efficiency of 29.3 mpg. The predicted 8.2 mpg increase from 1978 to 1985 can be divided between the advance of the frontier and changed vehicle attributes in two ways: (a) by predicting the effect of changed attributes and then the effect of the new frontier function or (b) by predicting the effect of the frontier function and then that of changed attributes. The first method allocates 49 percent of the mpg gain to the frontier's advance; the second allocates 39 percent.

CONCLUSIONS

There is considerable evidence that the goal of increasing automotive fuel efficiency by means of technological improvements was substantially achieved. It appears that the fuel efficiency technology frontier has advanced on all fronts and that this advance accounts for up to one-half of the total mpg gain. At the same time, however, the range of attribute bundles offered to consumers has been reduced by elimination of the heaviest and most powerful automobile choices. It is also clear that increased consumer demand for fuel economy played an important role. Consumers have not only accepted the improvements offered by manufacturers but have gone further, opting for still more efficient engine-drive-train configurations, nameplates, and size classes.

TABLE 5 ANALYSIS OF AUTOMOBILE MPG CHANGES BETWEEN CONSECUTIVE MODEL YEARS 1978–1986

		Difference in mpg Due to: Sales Shift		Configuration Information								
Beginning Model Year	Beginning mpg[a]	Between Classes	Within Classes	Efficiency Improvement	Sales Shift	Introduction	Discontinuation	Model Introduction	Model Discontinuation	Total Change in mpg	Ending mpg[b]	Ending Model Year
1978	19.73	0.37	0.24	–0.13	0.14	–0.03	–0.01	0.17	0.03	0.79	20.52	1979
1979	20.52	0.44	0.59	0.89	0.25	0.30	0.03	0.10	0.12	2.72	23.24	1980
1980	23.24	–0.18	0.36	1.04	0.04	0.08	0.01	0.59	0.08	2.03	25.27	1981
1981	25.27	0.14	–0.19	0.63	–0.04	0.38	0.02	0.07	0.05	1.06	26.33	1982
1982	26.33	–0.08	–0.10	–0.07	–0.13	–	0.08	0.12	–0.05	–0.22	26.11	1983
1983	26.11	–0.13	0.13	–0.14	0.13	–0.01	0.11	–0.02	0.15	0.23	26.33	1984
1984	26.33	0.23	–0.16	0.02	0.04	0.38	0.08	0.11	–0.06	0.64	26.98	1985
1985	26.93	0.15	0.40	0.21	0.28	0.09	0.03	–0.01	–	1.15	28.08	1986[c]
Total		0.94	1.27	2.45	0.71	1.19	0.32	1.13	0.33	8.35		

[a] Fuel economy of the beginning model year.
[b] Fuel economy of the ending model year.
[c] 1986 data are for the first six months of the model year.

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