ENERGY AND THE 55 MPH SPEED LIMIT--PRELIMINARY FINDINGS ON BENEFITS AND COSTS

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I. Introduction

After over two decades of growth and expansion in U.S. highway activity, the impact of the oil embargo from October 1973 to April 1974 was strikingly noticeable. Energy conservation instantly became a widespread concern with adjustments made individually as well as collectively through grovernment programs. Four years later the energy situation remains perplexing partly because we are uncertain what happened during and after the embargo. The purpose of this paper is to analyze in a systematic way one component of energy use, highway fuel consumption. Attention will be given to individual driver behavior and what is considered to be the most important relevant government program, the national 55 m.p.h. speed limit.

The paper is organized as follows: Section II presents a framework for analyzing highway travel by sketching a model of consumer utility maximization with minimization of trip costs as a subproblem. The implications of the embargo are noted. Empirical results of econometric analysis of the demand for highway fuel and speed of travel are given as supporting evidence. Section III reviews the theoretical case for the 55 m.p.h. limit and existing estimates of fuel savings interpreting them in light of the empirical work given in the previous section. Section IV is devoted to broader evaluation of the 55 m.p.h. limit which includes the reduction in traffic fatalities and the increase in travel time. Conclusions from the previous sections are discussed in this broader context.

II. Economics of Highway Travel

A. Household Production Model

The starting point of analysis in this paper is a simple model of driver behavior in which the individual maximizes his utility over consumption of travel and other goods subject to his limited endowments of money, time and health and the prices he faces. A person will divide consumption between travel and other goods so that the marginal utility per dollar spent on each is equal implying that when the price of travel increases the quantity demanded of travel will decrease. Total motor vehicle miles travelled increased 4.8 percent in 1970, 5.9 percent in 1971, 6.9 percent in 1972, only 3.2 percent in 1973 and decreased 1.5 percent in 1974, U.S. Bureau of Census (1977).

Moreover a traveller will choose cycle, car, bus, train, plane or whatever is the least costly mode of transportation by comparing the minimum cost at which travel on each mode can be produced. Costs he will consider are: money costs, time costs, safety costs, and comfort costs. Because the various modes are not perfect substitutes these costs can vary over some finite range without a switch of modes. For highway travel, a driver seeks to minimize his costs by using inputs in such a way that the value of marginal product is the same for each. He wants to obtain the same contribution to trip production for each of the car characteristics (such as average miles per gallon , miles per tune up, size, weight, and accessories) as from the speed of travel and effort expended while driving. Optimal short-run driver response to the embargo and consequent increase in fuel price is to reduce speed and intensify driving effort saving on relatively more expensive fuel and using more of relatively cheaper time. Given more time to respond, drivers will choose cars which give better gas mileage and further change the input mix.

While the model of highway travel has only been outlined, its features have well established precedents in the related works of Becker (1965, 1971), Blomquist (1977), Domencich and McFadden (1975), Gronau (1972) and Peltzman (1975) where many of the above implications are tested. In this paper, two implications of the highway travel model are tested in anticipation of the analysis of the 55 m.p.h. limit.

B. Demand for Highway Fuel

The derived demand for highway fuel can be viewed in terms of standard demand analysis such as that of Norling (1977). The U.S. per capita demand for highway fuel is estimated for the years 1937-41 and 1947-75 using two stage least squares and a Cochrane-Orcutt correction for first order serial correlation. Price of fuel, per capita income, and per capita stock of autos are explanatory variables while the variables, price of kerosene, price of distillate, price of residual oil, the tax on gas, per capita income, the price of autos and trend of fuel supply are used as instruments recognizing that the price of gas is endogenous. The results shown in Table 1 display a highly significant reasonable relationship for per capita highway fuel demand with a negative coefficient for the price of fuel and positive coefficients for income and the stock of autos as expected. The extimate of the elasticity of demand with respect to the price of fuel is -0.26 indicating that a 4 percent increase in price will be followed in the short-run by a bit more than a 1 percent decrease in fuel demanded.

TABLE 1

U.S. Demand for Highway Motor Fuel, QFQ
1936-41 and 1947-75

Variable	Coefficient	t-value	A Lower Bound of Significance Level
CQ	-5.223	-3.44	99%
PFQ	-0.255	-3.17	99
YQ	+0.268	+2.12	95
SAQ	+0.883	+7.00	99

R^2 = 0.999   n = 33

F = 8129.5   SEE = 0.01269

DW = 1.55

QFQ is the dependent variable. Variables are in natural logarithms and are defined in Table 2.

TABLE 2

Variables for Estimation of Fuel Demand

Variable	Definition	Mean Value	Units	Source
QFQ	Quantity of fuel for autos	0.2086	Gallons per person x 10^3	1
PFQ	Retail price of regular gas	0.3572	1967 dollars per gallon	2
YQ	Personal income	0.001873	1958 dollars per person x 10^6	3
SAQ	Stock of autos	315.5	Autos per person x 10^{-3}	4
PKQ	Relative price of kerosene	0.9731	Ratio of price of kerosene to wholesale price of gas (each in dollars per gallon)	5
PDQ	Relative price of distillate	0.8904	Ratio of price of distillate to wholesale price of gas	5
PRQ	Relative price of residual	0.3442	1967 dollars per gallon	5
TXQ	Tax on retail gas	0.1031	Index, 1936 = 1	-
TRQ	Trend	22.14	Index, 1967 = 1.000	6
PAQ	Price of autos	1.017	---	-
CQ	Constant	1.000		

All variables are in natural logarithms except TQ. The mean values are exp (log mean).

SOURCES: 1-Highway Statistics, 2-Petroleum Facts and Figures and Basic Petroleum Data Book, 3- Economic Report of the President, 4-Auto Facts and Figures and Motor Vehicle Facts and Figures, 5-Business Statistics, and 6-Survey of Current Business.

C. Highway Speed

In accordance with the model of highway travel a driver's optimal speed is the result of a calculus to produce trips at least cost. Increasing speed cuts down travel time, but beyond about 40 m.p.h. it increases gas consumption per mile and the risk of a fatal accident. For 1972, the last year before the oil embargo, the average speed on main rural highways and interstates is analyzed for 34 states with price of gas, income per capita, rural speed limit and population density as explanatory variables. (The number of state observations is limited by available data on the price of fuel and average highway speed.) The regression results shown in Table 3 depict a significant relationship where: the coefficient on the price of fuel is negative indicating that people drive more slowly while gas prices are high, the coefficient on per capita income is positive indicating that at the margin saving time is more important than the increase in risk of death, the coefficient on 1972 posted rural speed limit is positive which can be interpreted as reflecting driver response to safer highway conditions, and the coefficient on density is negative reflecting dangerous driving conditions. The result that the elasticity for income is the smallest of the three variables is consistent with the interpretation that an increase in income results in incentives to increase and decrease fuel consumption with the net result being ambiguous. Again the price of fuel is important with the elasticity of speed with respect to the price of fuel equal to -0.37

meaning that an 8 percent increase in price will result in a bit less than a 3 percent decrease in speed.

TABLE 3

Highway Speed of Travel, MPHS

Variable	Coefficient	t-value	A Lower Bound of Significance Level
CS	+4.374	+6.00	99
PFS	-0.373	-2.20	95
YS	+0.208	+3.15	99
SLS	+0.171	+2.04	90
DENS	-0.020	-2.70	98

R^2 = 0.611 n = 34
F = 11.38 SEE = 0.500

MPHS is the dependent variable. Variables are in logarithms and are defined in Table 4.

TABLE 4

Variables for Highway Speed Regression, 1972

Variable	Definition	Mean Value	Units	Source
MPHS	Average speed on main rural highways	60.16	Miles per hour	1
PFS	Retail price of gas	35.83	Cents per gallon	2
YS	Per capita personal income	4.154	Thousands of dollars per person	3
SLS	1972 rural speed limit	60.69	Miles per hour	4
DENS	Average population density	0.05221	Thousands of people per square mile	3
CS	Constant	1.000	-----------	–

All variables are in logarithms. Mean values are exp (long mean).

SOURCES: 1-Highway Statistics, 2-National Petroleum News, 3-U.S. Statistical Abstract, 1975, 4-Rand McNally Road Atlas, and Petlzman data.

III. Fuel Benefits of the 55 MPH Limit

While people coped with the oil embargo, resentment over the consequent adjustments was felt in Washington where the response was to formulate an energy program. One policy which emerged as a temporary measure, the Emergency Highway Energy Conservation Act of January of 1974, remains with us today as a permanent policy incorporated into Federal-Aid Highway Amendments. By March, 1974 all states had reduced the maximum speed limit to 55 m.p.h., with some voluntary reduction as early as November, 1973.

The reason for the 55 m.p.h. limit was to save fuel. The Federal Highway Administration (French and Bishop, 1974) estimated that between 100,000 and 200,000 barrels of oil per day would be saved with full compliance--a savings which amounts to about 3 percent of total U.S. fuel consumption for highway transportation. Behind the FHA and other estimates is the well-known relationship between vehicle speed and miles per gallon. For cruising at a constant speed in a standard car fuel use increases from 16.5 m.p.g. at 20 m.p.h., to 22.5 m.p.g. at 40 m.p.h., and then decreases to 17.3 m.p.g. at 70 m.p.h., and so on. Fuel use is of course greater for speeds below 20 and greater than 70 as well as for stop and go driving or driving in hilly areas. The EPA data and graph on fuel use and speed are shown below.

Without question there is good reason to believe that a reduction in speed will decrease fuel consumption and in fact highway fuel consumption did decrease in 1974. However, it is not clear that the decreased consumption can be attributed to the 55 m.p.h. limit. Mitre Corp. (1975) finds that while consumption was 255,000

TABLE 5

Vehicle Speed and Fuel Use

Type of Driving	Speed MPH	Fuel Use MPG
Urban Driving	20	10
Cruise	20	16.5
	30	20.0
	40	22.5
	50	21.5

TABLE 5

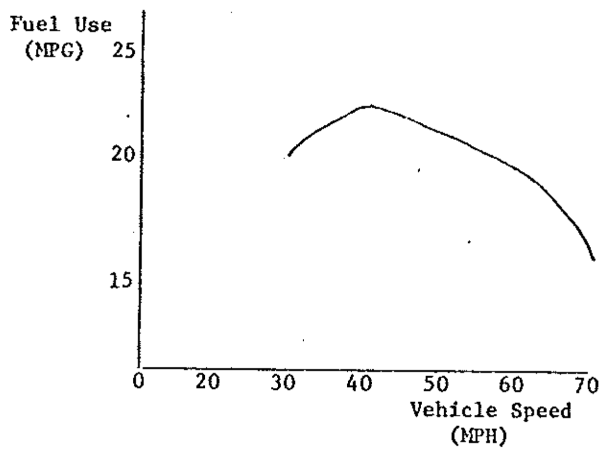
(continued)

Type of Driving	Speed MPH	Fuel Use MPG
	55	20.5*
	60	19.5
	65	18.4
	70	17.3

SOURCE: EPA (1973) *The fuel use for 55 m.p.h. is linearly interpolated from the EPA data.

FIGURE 1

Vehicle Speed and Fuel Use
(Cruise)



barrels per day lower in 1974 than 1973, an upper bound on the reduction due to the 55 m.p.h. limit and a switch to cars which get better gas mileage is 71,000 barrels (28% of the actual reduction). Braddock, Dunn and McDonald Inc. (1974) agree with the theoretical estimates of FHA but find no actual reduction due to the 55 m.p.h. limit. Nevertheless, in December 1976 the Federal Energy Administration (U.S. GAO, 1977 again emphatically supported the limit:

> The conclusions on the impact of the 55 m.p.h. speed limit on fuel consumption should point out that the 55 m.p.h. conservation measures we have, along with improving automotive fuel economy and increasing auto occupancy levels. Its importance in this area should not be understated, particularly since transportation consumes over half of this country's petroleum.

The demand analysis presented above indicates that the importance of the 55 limit has not been understated. Using the variance covariance matrix to construct a 95 percent confidence interval for 1974 QFQ shows the following where the values are given in levels instead of logs: 0.341 is the lower bound, 0.348 is the actual value, 0.354 is the fitted value, and 0.368 is the upper bound. Similarly the confidence interval for 1975 QFQ shows: 0.336 is the lower bound, 0.350 is the fitted value, 0.356 is the actual value, and 0.364 is the upper bound. While actual fuel consumption was less than expected in 1974 as one would predict if the 55 limit were effective, actual consumption was greater than expected in 1975, a year also covered by the 55 limit. In neither 1974 nor 1975 is the actual value outside the confidence interval, as the fitted value is only 0.9 standard errors from the actual value for each year. To further explore the effect of the 55 limit a dummy variable was created with 1974 and 1975 equal to 0 and 1936-41 and 1947-73 equal to one. The coefficient was not significantly different from zero at any reasonable confidence level, since the t-value was -0.64.

Another way of investigating the effect of the 55 limit is to estimate the fuel demand relationship for the period before any serious consideration of the 55 limit, predict fuel consumption for 1974 and 1975, and test whether or not the actual value is significantly different. The regression results reported in Table 6 show a relationship similar to that for the years 1936-41 and 1947-75. The noticeable difference is a larger price elasticity for the shorter period when gas prices changed slowly, e.g., 3 percent per year. Using the variance-covariance matrix to construct a 95 percent confidence interval for predicted 1974 QFQ gives the following where the values are in levels: 0.286 is the lower bound, 0.334 is the predicted value, 0.348 is the actual value, and 0.390 is the upper bound. For predicted 1975 QFQ the results are: 0.288 for the lower bound, 0.335 for the predicted value, 0.356 for the actual value, and 0.391 for the upper bound. Actual fuel consumption falls within the confidence intervals for 1974 and 1975 with predicted consumption 0.6 and 0.8 standard errors from actual consumption for the respective years.

Another indication of the small magnitude of the impact of the 55 limit on fuel consumption is given by cross-section analysis of states for 1973 and 1974, the pre and post 55 limit years respectively. Using price of gas, income, and stock of vehicles as before and also a variable for urbanization meant to reflect the high

TABLE 6

U.S. Demand for Highway Motor Fuel, QFQ
1936-41 and 1947-72

Variable	Coefficient	t-value	A Lower Bound of Significance Level
CQ	-4.109	-1.95	90%
PFQ	-0.442	-1.70	90
YFQ	+0.322	+2.21	95
SAQ	+0.716	+2.84	99

R^2 = 0.999 n = 30

F = 6118.5 SEE = 0.01295

DW = 1.57

QFQ is the dependent variable. Variables are in natural logarithms with definitions and sources given in Table 2.

gallons per mile of fuel consumption involved in city driving as well as the greater frequency of waiting for gas at stations in urban areas, preliminary results show reasonable relationships for 1973, 1974, and 1973-74 combined. An F-test indicates the relationship did not change significantly with implementation of the 55 limit.

The demand analysis indicates that changes in highway fuel consumption can be accounted for by changes in the explanatory variables excluding the 55 limit. For example using the 1936-41 and 1947-75 equation, the actual decrease in fuel consumption of 0.6 percent can be explained by driver response to the 23.1 percent increase in the relative price of gas, the 2.2 percent increase in real income and the 7.3 percent increase in the stock of autos. The predicted response to the price increase is a 5.9 percent decrease in fuel consumption, with 0.6 and 6.4 percent being the predicted increases in response of a 1.1 percent increase is not significantly different from the 0.6 percent actual decrease.

IV. 55 MPH Limit--Safety Benefits

While the 55 m.p.h. limit was introduced as part of a national energy policy, it is the reduction in traffic fatalities which is now lauded as the primary benefit of the regulation. According to Government Accounting Office (1977) report:

> The Safety Administration cites safety as the major accomplishment under the law, especially the dramatic reduction in fatalities in 1974 and 1975.

Indeed, according to the Federal Highway Administration (1975) the number of fatalities decreased from 55,113 in 1973 to 46,078 (-16%) in 1974 and to 45,500 (another -1%) in 1975. Actually the decrease in fatalities was not a complete surprise to traffic safety specialists, since it is widely accepted that increases in speed increase accident severity. The decrease in fatalities did stimulate interest in quantifying that relationship. Council and Waller (1974) report that for North Carolina accidents in 1973 the number of fatalities per accident increases with estimated speed before impact. The fatality rate for 56-60 m.p.h. is 30% greater and the rate for 61-65 m.p.h. 60% greater than the 51-55 m.p.h. rate while the 71-75 m.p.h. rate is 5 times and the 76-80 m.p.h. rate 7 times. Peltzman (1975) using 1947-65 data for the U.S. estimates the elasticity of the total number of traffic deaths per vehicle mile with respect to average speed on main rural roads to be +1.8. Approximately the same elasticity estimate is implied by Enustun and Yang (1975) in their regression analysis of October 1972 to April 1974 monthly accident data for Michigan.

Factors other than reduced speed contributed to the decrease in fatalities. With the oil embargo came a decrease in vehicle miles travelled especially for pleasure trips for which the probability of a fatal accident is particularly high. The National Safety Council (Tofany, 1975) attributes the decrease in fatalities to various factors as shown in Table 8. Similar studies by the American Association of State Highway and Transportation Officials (1974) and General Motors (Carpenter, 1974) also concludes the reduction in speed was the most important factor as does Tihansky (1974). In view of these studies and the established relationship between speed and accident severity, it is not surprising that using analysis of variance of Utah highway fatalities Labrum (1976) concludes that

TABLE 7

Vehicle Speed and Fatality Rate

Speed (MPH)	Fatality Rate (Fatalities/accident)	Rate ÷ 51-55 Rate
51-55	.0317	1.0
56-60	.0183	1.3
61-65	.0212	1.6
66-70	.0407	3.0
71-75	.0688	5.0
76-80	.0931	6.8
81-85	.1135	8.3

TABLE 7

(Continued)

Speed (MPH)	Fatality Rate (Fatalities/accident)	Rate ÷ 51 - 55 Rate
86-90	.1531	11.2
90+	.2260	16.5

SOURCE: Council and Waller (1974)

TABLE 8

Factors Contributing to Reduced Fatalities in U.S. January-April 1974 vs January-April 1973

Contributing Factor	Percent Due
Reduction in speed	-46
Reduction in travel	-21
Reduction in vehicle occupancy	-13
Change in day-night travel	-8
Change in type of road used	-4
Increased use of safety belts	-4
Other	-8
Motorcycles, pedalcycles, small car and age of driver	+4
TOTAL	100

SOURCE: National Safety Council (Tofany, 1975)

1974 highway travel conditions are different from those in 1971-73. What is surprising is that no one has asked a more penatrating question than, "Did the reduction in speed affect highway fatalities?", namely "Would the reduction in speed have occurred without the 55 m.p.h. limit?"

Recall from the model of highway travel outlined earlier, that one response to an increase in the price of fuel is to reduce speed to decrease fuel consumption per mile, i.e., drivers too are aware of the speed-m.p.g. relationship illustrated with the EPA data. The regression analysis of 34 states for 1972 reveals that speed is inversely related to the price of fuel and that the elasticity of speed with respect to price is -0.373. If we are bold enough to use this elasticity to predict driver response to the 23.1 percent increase in the real price of fuel from 1972 to 1974, we would anticipate an 8.6 percent reduction in speeds.

According to the Federal Highway Administration (1972 and 1974) average speed on main rural roads including interstate highways fell from 60.3 in 1972 to 55.3 in 1974, an 8.3 percent decrease. In other words, the deduction in speed during 1974 could well have been due to driver response to the high fuel price. Since the price increase and 55 m.p.h. limit occurred together it is difficult to say that the speed reductions and consequent reduction in traffic fatalities was due to the government's energy conservation measure. However, a distinguishing implication of the model of highway travel is that the optimal speed increases as the price of fuel falls. In 1975 the real price of fuel did not increase from the 1974 level and in 1976 the real price fell 3.4 percent. While published data on speeds is not readily available, one would surmise from casual observation that speeds are increasing above 55 m.p.h., something which should not occur with the national limit. The tremendous increase in CB sales is at least partly motivated by the optimal speed for the driver being above the legal limit. Here in Illinois we read (Baker, 1977) of a car driven 215 miles on interstates at 55 m.p.h. and being passed by 325 vehicles including a drivers' education car, a church bus, a car with official House of Representatives license plates, two Illinois Department of Transportation cars and passing none itself.

V. 55 MPH Limit--Benefits and Costs

To this point, the model of highway travel has been used to predict driver response to the oil embargo and evaluate the claimed fuel and safety benefits of the 55 m.p.h. limit. Something explicit in the model and conveniently ignored by many who analyze the 55 m.p.h. limit is that the reduced speed tends to raise the cost of a trip by the value of the added travel time. For a nation which spends as much as it does constructing new urban and rural freeways to facilitate travel this slight of time costs is an anomoly. Acutely aware of time costs are those whose incomes depend on travel time. It is no surprise that in the Wall Street Journal (Karr, 1976) one trucking firm reports 67 percent of its drivers exceeding the 55 m.p.h. limit and 30 percent exceeding 60 m.p.h. and further that it is the independent truckers (who are not paid by the hour) who protest most vociferously. To gain perspective on the benefits of reduced speeds, let us consider the magnitude of the time costs for the nation in 1974.

The procedure for calculating time costs for rural driving is as follows: (a) Using the data on the distribution of drivers traveling at speeds over 55 m.p.h. and the number of miles travelled on rural highway, calculate the time it would take the fast (55+) drivers to travel the number of miles travelled in 1974 at 1973 speeds. (b) Calculate the travel time for the fast drivers to travel the 1974 miles at 1974 speeds. (c)

Subtract 1973 time from 1974 time and multiply those hours of additional travel time by a value of time, which varies with income and the number of occupants in each vehicle. Preliminary calculations indicate that the value of additional 1974 travel time is approximately $900 million in 1977 dollars. These certainly must be considered in any evaluation of the 55 m.p.h. limit.

In this paper a simple model of highway travel is outlined. Optimal driver response to the oil embargo of 1973-74 was found to be a reduction in the amount of travel, a reduction in fuel consumption because of less travel and because of a switch to producing trips with less fuel by reducing speed. Highly significant regression results from analysis of fuel demand and speed support the model. Surprisingly it is found that the reduction in fuel consumption and speeds from 1972 to 1974, often attributed to the 55 m.p.h. limit, can be explained by driver response to the 23 percent increase in the price of fuel and as well as changes in income and other variables. It was noted that the much-neglected time costs of the reduced speeds in 1974 is a nontrivial $900 million.

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