Effects of Policy Related Variables on Traffic Fatalities:
An Extreme Bounds Analysis Using Time Series Data*

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RRH: EFFECTS OF POLICY VARIABLES ON TRAFFIC FATALITIES
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ABSTRACT

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This study finds that reducing speed limits (to 55 mph) in the U.S. results in a reduction of fatality rates. In addition, the proportion of newer vehicles on the highways (subject to newer safety regulations) has a significant effect on fatality rates. The analysis is conducted using extreme bounds analysis applied to a time series model of the determinants of U.S. fatality rates. This model incorporates many policy and socio-economic variables.

I. Introduction

The determinants of automobile related fatalities have been
of great interest among economists, statisticians and government
officials lately. Statistical models and techniques of various
degrees of sophistication have been employed to evaluate the
potential contributing effects of a host of socioeconomic and
policy related variables on motor vehicle fatality rates.[1] Loeb
[17; 18; 19; 20], Loeb and Gilad [21], Fuchs and Leveson [10] and
Crain [5] evaluated the impact of motor vehicle inspection on
fatality rates. The Loeb and Loeb and Gilad studies found
inspection to have a significant impact on reducing various
measures of fatalities as measured by the significance and
stability of the coefficient associated with the inspection
variable across various specifications. Furthermore, both Crain
and Fuchs and Leveson also found some support for the effective-
ness of inspection, although Crain does not favor inspection.
More recently, Keeler [12] found inspection to be effective in
reducing fatalities in 1970 but not in 1980.

The effect of raising the minimum legal drinking age (MLDA)
was evaluated by Cook and Tauchen [4], Asch and Levy [1; 2] and
Loeb [19]. Cook and Tauchen found that reducing the MLDA
resulted in an increase of fatality rates among youthful drivers.
Asch and Levy, as well as Loeb, found the effect of the MLDA on

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fatality rates either smaller or less significant than reported by others.[2]

In general, alcohol consumption has been found to have the expected effect on fatality rates, i.e., higher alcohol consumption is associated with higher fatality rates.[3] Interestingly, Fowles and Loeb [8] found an interactive effect of altitude and alcohol on traffic fatality rates.

Finally, the literature evaluates the effect of motor vehicle speed, generally measured as the average speed of free moving vehicles on rural interstate highways. The reported results indicate that speed is positively and significantly associated with fatality rates. This was demonstrated directly by both Loeb [18; 19], Fowles and Loeb [9], and Sommers [26]. The effects of speed and speed variance have been addressed by Lave [13; 14], Levy and Asch [16], Fowles and Loeb [9], Synder [25], Rodriguez [24], and Keeler [12]. The effect of speed has gained more recent public attention with the March 1987 Congressional Hearings resulting in possible changes of the maximum speed limit on rural interstate highways. Forester, McNown and Singell [6] evaluated the 55 mph speed limit using a three equation recursive model. They conclude that the 55 mph speed limit is not cost-effective, although they find the net impact of the speed limit is a reduction in fatalities. This latter result may be compared with findings of Loeb [18; 19], Sommers [26], and

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Keeler [12].

Many of the specifications utilized in the above studies use an assortment of socioeconomic variables in addition to driving and policy related variables. Due to problems of collinearity between the regressors, conclusions are sensitive to model specification.[4] From a traditional econometric perspective, results are suspect due to variable omission bias. In this paper we examine the fragility of various policy related and socioeconomic variables in regression specifications using Bayesian extreme bounds analysis as developed in Leamer [15].

II. The Model

In order to evaluate the effect of several policy related variables on fatality rates, a log-linear time series model of the following form is considered for forty years beginning in 1952:[5]

$$\ln(\text{Fatality Rate}_t) = \beta_0 + \beta_1 \ln(\text{PRDINS})_t +$$

$$\beta_2 \ln(1+\text{SPDLMT}_t) + \beta_3 \ln(\text{MLDA}_t) + \beta_4 \ln(\text{AGE}_t) +$$

$$\beta_5 \ln(\text{ALCH}_t) + \beta_6 \ln(1+\text{VEQUIP}_t) + \beta_7 \ln(\text{PRICE}_t) +$$

$$\beta_8 \ln(\text{INTRST}_t) + \beta_9 \ln(\text{DDINC}_t) + \beta_{10} \ln(1+\text{BELTS}_t) +$$

$$\beta_{11}(\text{UNEMPLOY}_t) + \varepsilon_t$$

where:

Fatality Rate$_t$ = the number of traffic fatalities per

100 million vehicle miles of travel in the tth year.

$PRDINS_t$ = ratio of automobiles subject to

safety inspection to total registered auto-

mobiles.

$SPDLMT_t$ = 55 mph binary variable.

$MLDA_t$ = median minimum legal drinking age for purchas-

ing beer.

AGE_t = ratio of 16-24 year olds to population

of age 16 or over.

$ALCH_t$ = per capita consumption of alcoholic

beverages.[6]

$VEQUIP_t$ = ratio of 1966 or newer registered vehicles to

total registered vehicles.

$PRICE_t$ = accident price data based on a weighted aver-

age of medical care and automobile repair components of

the CPI divided by the total CPI.[7]

$INTRST_t$ = miles of highway in the interstate system.

$DDINC_t$ = real disposable personal income per driver (in

thousands, 1972=100).

$BELTS_t$ = ratio of automobiles subject to seat belt

legislation to total registered automobiles.

$UNEMPLOY_t$ = US overall unemployment rate.

β_j (j=0,...,11) = 12 parameters to be estimated.

ε_i = a random error term.[8]

    Two categories of model specifications are considered. A policy related specification focuses attention on variables related to government control. A socioeconomic specification looks at variables related to demographic, income and "price" measures of an accident. For both categories, we separate the variables into two sets. The first set consists of variables that would typically be included in any regression specification under that category (policy or socioeconomic). These are con-sidered free variables; they are included because their effects are believed to be important. The remaining variables are considered doubtful; these variables may or may not be included in a particular specification.

    From a Bayesian perspective, well defined priors exist for the expectation of the coefficients on the set of doubtful vari-ables. They are centered at zero, reflecting the opinion that the effect of a doubtful variable is small. Priors are com-pletely diffuse for the set of free variables.

    Table I defines the set of variables along with *a priori* expected effects on fatality rates.[9] Analysis is based on data for the years 1952 to 1991 aggregated across all states.[10]

III. Extreme Bounds Analysis

In this section we derive sets of posterior means for minimally specified priors on the set of doubtful variables. Beyond consideration for inclusion or deletion in a regression specification, prior opinions about the effects of variables are typically not well defined. Due to collinearity between the regressors, the effect of dropping or adding variables in a regression equation is not inconsequential and gives rise to the issue of selective reporting. Extreme bounds analysis addresses this problem by reporting the maximum and minimum values that could be obtained via maximum likelihood estimation on the free set of variables when all possible linear combinations of variables from the doubtful set are considered. This is developed by Leamer [15] using a Bayesian natural conjugate prior on the set of doubtful variables.[11] For the normal linear regression model

$$Y \sim N(X\beta, \sigma^2 I),$$

the prior mean on the p doubtful variables is also normal, centered at zero, with variance matrix H^{*-1}. This is written as

$$R\beta \sim N(0, H^{*-1})$$

where R is a pxk matrix of constants, β is a kx1 vector of parameters, 0 is a px1 zero vector, and H^* is a pxp positive definite symmetric precision matrix (the inverse of the variance matrix). Leamer [15] shows that extreme values of linear functions of the posterior mean for the kx1 vector τ,

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$$\tau'b** = \tau'(H + R'H*R)^{-1}Hb$$

are given by

$$a + \tau*'f \pm (\tau*'A^{-1}\tau*c)^{.5}$$

when $H*^{-1}$ is constrained to fall between positive definite matrices Vl and Vh and

$$a\quad = \tau'b - \tau'H^{-1}R'(RH^{-1}R')^{-1}Rb,$$

$$\tau*'\ = \tau'H^{-1}R'(RH^{-1}R')^{-1},$$

$$f\quad = (h + Vl^{-1})^{-1}(hRb + (Vl^{-1} - Vh^{-1})\ *$$

$$(h + Vh^{-1})^{-1}hRb/2),$$

$$A\quad = (h + Vh^{-1})(Vl^{-1} - Vh^{-1})^{-1}(h + Vh^{-1})\ +$$

$$(h + Vh^{-1}),$$

$$c\quad = (Rb)'h(h + Vh^{-1})^{-1}(Vl^{-1} - Vh^{-1})(h + Vl^{-1})^{-1}hRb/4,$$

$$h\quad = (RH^{-1}R')^{-1},$$

$$b\quad = (X'X)^{-1}X'Y,$$

$$H\quad = s^{-2}X'X,$$

$$s\quad = ((Y-Xb)'(Y-Xb)/(n-k))^{.5}.$$

Tables II and III summarize extreme bounds analysis for both prior categories for the free parameters as a function of Vl and Vh computed by MICRO-EBA [7]. In addition, Tables II and III report "reasonable" bounds which are the maximum and minimum values for the posterior mean computed on 99% joint likelihood ellipsoids.[12] The widest possible bounds occur at $Vl = 0H*^{-1}$ and

$Vh = \infty H^{*-1}$. Note that priors are minimal in this reporting style since H*, the prior precision matrix, is only required to be positive definite symmetric.[13] Results are only sensitive to the free-doubtful mix via the R matrix which reduces the dimensionality for the prior space from k to p. Various free--doubtful combinations are considered.

As can be readily seen in the policy prior, only extreme bounds for SPDLMT are tight and in accord with *a priori* expectations. Upper and lower bounds computed on a 99% likelihood ellipsoid are tight for both SPDLMT and VEQUIP. Under the socioeconomic prior, extreme bounds are tight for UNEMPLOY and VEQUIP. Likelihood bounds are tight for UNEMPLOY, VEQUIP, and SPDLMT computed on a 99% likelihood ellipsoid. Note that SPDLMT is a doubtful variable for the socioeconomic prior, but is non-fragile over "reasonable" bounds. This enhances the evidence that SPDLMT is an important explanatory variable.

For comparison, least squares estimates for the full model with 12 variables are reported in Table IV.[14] From a classical perspective, the estimated coefficients for UNEMPLOY, AGE, SPDLMT, VEQUIP, INTRST, and PRICE are statistically significant at or above the traditional 95% confidence level. All variables in this category have signs that are in accord with a priori expectations.[15]

III. Conclusion

In this paper we find the effects on fatality rates of the 55 mph speed limit and the relative number of registered newer vehicles on the highway to be negative and significant. Most importantly, these results are non-fragile across a large set of reasonable alternative specifications based on reasonable bounds analysis on a 99% likelihood ellipsoid. As such, government officials might be cautious in developing policy recommendations which would result in higher average speeds, such as raising speed limits, since such recommendations are likely to result in an increase in fatality rates.[16] In addition, the effects on fatality rates of the youthful component of the population, the 55 MPH speed limit, the price of an accident, interstate highway mileage, the newer safety criteria (which VEQUIP measures), and the unemployment rate have statistically significant coefficients and were found to be consistent with a priori expectations based on regression evidence presented in Table IV.

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Footnotes

Table I. Symbols and Definitions

Symbol	Definition	Expected Effect on the Dependent Variable
PRDINS	Ratio of automobiles subject to safety inspection to total registered vehicles.	<0
SPDLMT	55 mph dummy variable (1 when 55 mph speed limit in force, 0 otherwise).	<0
MLDA	Median minimum legal drinking age for purchasing beer.	<0
AGE	Ratio of 16-24 year olds to the population of age 16 or over.	>0
ALCH	Per capita consumption of alcoholic beverages.	>0
VEQUIP	Ratio of 1966 or newer registered vehicles to total registered vehicles.	<0
PRICE	Relative price index of an accident based on components of the CPI.	<0
INTRST	Miles of highway in the interstate system.	<0
DDINC	Real disposable personal income per driver (in thousands, 1972=100).	⋛0
BELTS	Ratio of automobiles subject to seat belt legislation to total registered vehicles.	<0

Table II. Extreme Bounds for the Bayesian Posterior Mean for Free Variables:
Policy Prior*

FREE VARIABLE	UPPER BOUND	LOWER BOUND	99% UPPER BOUND	99% LOWER BOUND
CONSTANT	14.977	-6.718	10.586	-2.052
ALCH	3.428	-2.258	2.193	-1.119
BELTS	0.467	-0.774	0.344	-0.345
PRDINS	0.941	-1.532	0.718	-0.641
SPDLMT	-0.140	-0.618	-0.169	-0.421
VEQUIP	0.274	-1.511	-0.064	-1.102
MLDA	0.308	-0.845	0.308	-0.076

* The set of doubtful variables includes DDINC, UNEMPLOY, PRICE, INTRST, AGE.
No doubtful variables were tight on 99% bounds.

Table III. Extreme Bounds for the Bayesian Posterior Mean for Free Variables:
Socioeconomic Prior*

FREE VARIABLE	UPPER BOUND	LOWER BOUND	99% UPPER BOUND	99% LOWER BOUND
CONSTANT	8.910	−1.715	8.799	−1.140
DDINC	0.779	−0.940	0.594	−0.940
UNEMPLOY	−0.107	−0.237	−0.107	−0.210
PRICE	0.161	−2.035	0.161	−1.800
VEQUIP	−0.201	−1.130	−0.205	−1.065
AGE	2.102	−0.310	2.059	−0.212

* The set of doubtful variables includes ALCH, INTRST, BELTS, PRDINS, SPDLMT, MLDA. SPDLMT was tight on 99% bounds: Upper = -0.041, Lower = - 0.793.

Table IV. OLS Results for the Fatality Rate Model*

VARIABLE NAME	ESTIMATED COEFF	STANDARD ERROR	|T| STATISTIC
CONSTANT	4.298	1.204	3.568
DDINC	-0.361	0.266	1.358
AGE	0.980	0.242	4.047
SPDLMT	-0.275	0.040	6.954
VEQUIP	-0.557	0.113	5.109
PRDINS	0.116	0.181	0.641
PRICE	-0.582	0.234	2.490
ALCH	0.526	0.337	1.559
INTRST	-0.083	0.021	3.958
MLDA	0.277	0.162	1.703
BELTS	0.035	0.080	0.439
UNEMPLOY	-0.136	0.028	4.764
AdjRSQ	0.954		
SE	0.025		
DW-STAT	1.477		

* Natural logarithms used for all variables.

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1. See, for example, Keeler [12], Loeb [19; 20] and Loeb and Gilad [21] for a discussion.

2. See Loeb [19] for a further discussion.

3. See Loeb [19] and Sommers [26].

4. See Loeb [18].

5. See Loeb [17] for a classical analysis of alternative models.

6. The model was also evaluated using beer consumption in place of alcohol consumption. The beer results do not vary substantially from those reported here and are available from the authors.

7. In this paper the weights for medical care and automobile repair were .74 and .26 respectively. These weights are based on relative expenditures for 1980. See Peltzman [22] for a

discussion on the lack of sensitivity of results to various weighting schemes. Alternative measures of the price of an accident have been suggested which incorporate an insurance loading factor. See Loeb [17] or Zlatoper [27]. We examined in place of our accident price one such measure developed by Zlatoper using data from the period 1952 to 1985. Results do not vary substantially using this measure and are available from the authors.

8. Given that the model is in double log from, a "1" was added to the value of binary and ratio variables whose observation could take on a value of zero.

9. See Jackson, Loeb and Franck [11] for a further discussion of the variables and their expected effect on the dependent variable.

10. Data sources are as follows:

Fatality Rate: National Safety Council, *Accident Facts*, Chicago, Illinois.

DDINC: National Safety Council, *Accident Facts*, Chicago, Illinois and *Economic Report of the President*, (various issues), U.S. Government Printing Office, Washington, D.C.

AGE: U.S. Bureau of the Census (various issues), *Statistical Abstracts of the United States*, Washington, D.C., and U.S. Department of Commerce, Bureau of the Census (various issues), *Current Population Reports*, Series P-25, U.S. Government Printing Office, Washington, D.C.

VEQUIP: *Motor Vehicle Facts and Figures* (various issues).

PRDINS: U.S. Department of Transportation, Federal Highway Administration, *Highway Statistics*, (various editions), U.S. Government Printing Office, Washington, D.C. for vehicle registrations. Data on states having some form of inspection, by year, was provided by Motor Vehicle Manufacturers Association of the United States, Inc., Detroit, Michigan.

PRICE: U.S. Bureau of the Census (1975), *Historical Statistics of the United States, Colonial Times to 1970*, Bicentennial Edition, Washington, D.C. and U.S. Bureau of the Census (various issues), *Statistical Abstracts of the United States*, Washington, D.C.

ALCH: Data on alcohol consumption from National Institute on Alcohol Abuse and Alcoholism. Population data from U.S. Bureau of the Census (various issues), *Statistical Abstracts of the United States*, Washington, D.C., and U.S. Department of Commerce, Bureau of the Census (various issues), *Current Population Reports*, Series P-25, U.S. Government Printing Office, Washington, D.C.

UNEMPLOY: U.S. Bureau of the Census, *Statistical Abstracts of the United States*, Washington, D.C.

INTRST: U.S. Department of Transportation, Federal Highway Administration (various editions), *Highway Statistics*, U.S. Government Printing Office, Washington, D.C.

MLDA: Data on the minimum legal drinking age were provided by the Distilled Spirits Council of the United States.

BELTS: *Motor Vehicle Facts and Figures.*

11. See Raiffa and Schlaifer [23] for a discussion on natural conjugate priors.

12. Complete EBA results which present values for the extreme bounds on a wide grid as well as extreme bounds computed over other common likelihood ellipsoids are available from the authors.

13. This is discussed in Chamberlain and Leamer [3] and in Leamer [15].

14. Only a partial set of all results are provided due to space limitations. Additional results, consistent with those reported, are available from the authors.

15. We note that since approximately half of automobile fatalities involve alcohol, the amount of drunk driving almost certainly is related to fatality rates. The lack of significance associated with the coefficient of the alcohol variable (per capita consumption of alcoholic beverages) probably means that this often-used variable is a poor measure of drunk driving frequency.

16. Note that the results pertaining to speed limits were non-fragile even when using maximum extreme bounds, i.e., analysis on 100% likelihood ellipsoids.