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Publication Date
1991-03-01

Peer reviewed

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Working Paper No. 91-161

**Highway Safety, Economic Behavior,
and Driving Environment**

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March 1991

Key words: Automobile regulation, highway safety, economics of health, transportation safety

JEL Classification: 615, 913, 916

Abstract

This paper contributes to the literature on economic aspects of highway safety in two important ways: first, it extends the consumer-theoretic model of safety behavior to show that the effects of regulation are likely to differ by driving environment, and it predicts the directions of those differences. Second, it tests the effects of regulatory policies on highway safety in differing driving environments, using a large (county-based) data set (for 1970 and 1980). In addition, the analysis contributes to a literature on the demand for safety relating income, education, and other non-regulatory variables. The results indicate considerable evidence that consumers offset regulations with their driving behavior, with respect to vehicle safety regulation, speed limit (which was found to affect fatalities only in high-density environments and not at all in rural areas) and with respect to certain other regulations, such as vehicle inspection programs. Other regulatory policies, such as minimum drinking age, had substantial effects in reducing fatalities, especially in 1980. Income and education are shown to have the effects on fatalities predicted by economic theory. Finally, the results show (consistent with the theory presented) that driving environment has a strong effect on safety, and interacts with regulatory and other variables in its effects on safety.

HIGHWAY SAFETY, ECONOMIC BEHAVIOR, AND DRIVING ENVIRONMENT

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March, 1991

Economic analysis has made an important contribution by enhancing our understanding of the efficacy of highway safety regulations. Specifically, a consumer-theoretic literature has developed which has illuminated the debate on drivers' responses to regulations, as developed by Peltzman (1975). Meanwhile, an empirical literature has also developed, testing hypotheses relating to speed limits, safety-device regulations, and alcohol policies, among other things.[1] Yet, despite extensive theoretical and empirical research, strong controversies remain as to the effects of regulations on highway safety, and as to the economic desirability of those regulations.

This paper contributes to the literature on economic aspects of highway safety in two important ways: first, it extends the consumer-theoretic model of safety behavior to show that the effects of regulation are likely to differ importantly by driving environment, and it predicts the directions of those differences. Second, it tests the effects of regulatory policies on highway safety in differing driving environments, using a larger (county-

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[1]Peltzman also contributed to this emprical literature, which is quite extensive. Recent examples include a series of articles in the AER, starting with Lave (1985) and including Fowles and Loeb (1989), Levy and Asch (1989) and Snyder (1989).

based) data set than has been used by previous studies. In addition, the analysis contributes to a literature on the demand for safety relating income, education, and other non-regulatory variables. In this dimension, as well, the analysis shows that driving environment can be an important determinant of highway safety.

The results shed new light on the consumer-theoretic model of highway safety behavior and on the effectiveness of regulatory policies (including speed limits safety device requirements, and minimum drinking ages, among other things). Furthermore, the study contributes to the literature on health and safety, showing more clearly the effects of income and education the demand for safety. An important theme of the study, theoretically and empirically, is that differences in driving environment are likely to have important effects on the response to regulation, and these differences should be taken account of, both in modeling and in public policy.

The next section of this paper summarizes the consumer-theoretic model of Peltzman (as extended by Viscusi and Blomquist) and then examines its implications for the effects of regulation in urban versus rural environments. We discuss its implications both for safety-device regulations (such as seat belts) and for other types of regulation, such as speed limits.

The second section is concerned with appropriate specification of the cross-sectional equations to be estimated,

and the third with data and issues of estimation.

The fourth section presents the results, and the fifth considers the implications of our results, both for the existing literature on economic aspects of highway safety, and for public policy.

I. ECONOMIC ANALYIS OF MOTOR VEHICLE SAFETY

In this section, we summarize the Peltzman-Viscusi-Blomquist[2] model as developed earlier, then analyze its implications for the equations to be estimated here. The purpose of the approach is to model the driver's behavior towards safe versus unsafe behavior under conditions of risk. In the simplified model, there are two possible states (outcomes): first, an accident can occur (with probability P) or not occur (with probability 1-P). The probability that an accident will occur is influenced by the driver's behavior and by regulation. Each variable requires further discussion.

The driver's effort at achieving safety (denoted by e) is strongly connected to the time it takes to make an average trip

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[2]Peltzman developed the original model, emphasizing effects of regulation on the size of an expected loss for a given probability of an accident. Viscusi (1984) emphasizes the probability of an accident, with a given expected loss. Blomquist (1989) incorporates allows both probability and size of loss as variables in his model. The present model is most similar to that of Blomquist, but, for simplicity, it subsumes both loss level and probability into a single function.

by car. A safer trip is very often a slower one, if not because of differences in speed on the straight-of-way (more about that later), then because of slower acceleration and gentler braking, and taking curves at lower speeds. Even time spent fastening seat belts is onerous for many motorists. Thus, in the context of an expected utility model, we denote the disutility of this effort as $V(e)$, with $V'(e)>0$, $V''(e)>0$. On the other hand, holding consumer behavior constant, a government regulation (such as a required safety device) is will generally improve safety and reduce the probability of an accident. If we let r denote the stringency of government regulations, then the probability of an accident can be written $P = P(e, r)$, where e is effort made to achieve greater levels of safety levels and r is a variable reflecting a government regulatory requirement (such as required expenditures on safety devices per vehicle).

The loss from an accident, if it occurs, is also a function of the same two variables, so $L = L(e,r)$. We shall discuss the expected signs of the derivatives of the probability and loss functions below.

Then (assuming risk neutrality), the motorist maximizes the following

$$U = P(e,r)[I - V(e) - L(e,r)] + [1-P(e,r)][1-V(e)] \qquad (1)$$

or

$$U = I - V(e) - P(e,r)L(e,r) \qquad (2)$$

where U expected utility, which is income minus the disutility of effort to avert an accident minus the expected loss from an accident.

Note that there is no loss of generality (and some gain in simplicity) by defining a function $C(e,r) = P(e,r)L(e,r)$. C then represents the expected cost of accidents in the expected utility model. Given our assumptions, it is reasonable to assume that C_e < 0, that is, that extra effort towards safety generates lower expected accident costs. Similarly, it is reasonable to assume C_{ee} > 0, that is, that the marginal reduction in cost from additional effort decreases with more effort. Furthermore, we assume that C_r < 0 and C_{rr}>0. Finally, we assume that C_{er} > 0, that is, that a safety-enhancing regulation reduces the marginal benefits of a unit of safety effort.

Maximum utility then requires maximizing the following expression:

$$U = I - V(e) - C(e,r) \tag{3}$$

Maximization of this expression requires that dU/de be set equal to zero, or

$$-V_e = C_e \tag{4}$$

This simply indicates that the driver will trade off the

disutility of efforts towards improved safety against the benefit

of those efforts in the form of reduced expected accident costs.

We now wish to focus on the effects of a shift in government

regulation on safety effort on the part of the motorist. To find

that, we treat (4) as an implicit function and find de/dr:

$$de/dr \quad = -[-C_{er}/(-C_{ee}-V_{ee})] \tag{5}$$

$$= -C_{er}/(C_{ee} + V_{ee}) \tag{6}$$

The term C_{er} in the numerator of (6) is assumed to be

positive, and the denominator is similarly positive from our

assumptions. Therefore, the offsetting effect will be negative.

That is, an increase in safety-enhancing regulation reduces

effort towards safety on the part of the driver.   Similarly,

exogenous forces decreasing safety will increase e.

The size of the effect shown here is difficult to determine.

In Peltzman's original formulation, he noted that it is quite

possible (but not inevitable) that the reduced effort induced by

the safety regulation could offset the benefits of the

regulation. This is especially so when externality costs (i.e.,

to pedestrians and bicyclists) of the less safe behavior are

accounted for. In any event, it should be evident that even of

the effects of regulation are not fully offset through this

effect, they will be reduced.

Although Peltzman and others have applied this analysis most especially to safety-device regulation (such as seat belts and airbags), it should be evident that it is applicable in other areas of auto safety regulation. For example, some offsetting behavior might well be possible with speed limits (faster acceleration, braking, and cornering, as well as evasion, which is similar to but goes further than offsetting behavior). Similarly, vehicle inspection programs could induce offsetting behavior, as could numerous other forms of regulation.

This paper will test for offsetting behavior for several of these regulations, including safety devices, speed limits, inspection programs, and license renewal testing.

More importantly, because the present study is able to distinguish between urban and rural environments, it will also be able to test an attribute of offsetting behavior which previous studies have not. To see that, let us consider ways in which offsetting behavior could be expected to differ theoretically between the two environments. Both intuition and equation (6) shed light on why and how.

Suppose a motorist tried to achieve offsetting behavior in each environment. Specifically, suppose a regulation were imposed in an attempt to enhance safety in each environment. How would the environments affect the motorists' reponse? There are numerous possible differences, but one stands out: as the motorist tries to reduce safety effort (i.e., drive and

accelerate faster), the urban environment is likely to impose

severe obstacles not present in the rural one: if the motorist

tries to move faster than the traffic and stoplights permit, the

dangers rise very rapidly, while the possible saving in time is

still minimal. Such constraints are much less likely to occur in

a rural environment. This suggests that the urban motorist will

likely be frustrated much more quickly in his/her attempt to

offset regulations than will the rural driver. The implications

of this for offsetting behavior can be seen analytically from

(6).

First, the numerator term, C_{er}, will be smaller (in absolute

value) in urban environments than in rural ones. That is, the

marginal benefit of a unit of safety effort will be reduced less

by regulation in the urban environment than in the rural

environment.

Second, the first term of the denominator, C_{ee}, will be

greater in the urban environment than in the rural environment.

This simply means that reduced safety effort (independent of

regulation) will cause the marginal cost of accident losses to

rise more rapidly in an urban environment than in a rural one,

even if the accident cost function had the same level and slope

for both environments.[3] Figure 1 illustrates this point in the

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[3]As indicated below, the empirical evidence indicates that, all
other things equal, the fatality rate decreases with population
density. Yet it can still be argued a priori that effects of
increased or decreased safety effort as outlined in the text are
the stronger ones, and, as we shall also see, there is empirical

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context of the curvature of the function relating the probability of an accident to safety effort, with alternative curves for urban and rural environments (assume that regulation is held constant at a particular level for purposes of this graph, so that we are observing the slope and curvature of the C function with respect to e, holding r constant). Consistent with our assumptions, the levels and slopes of the curves are shown to be the same at the point of equilibrium. However, the differing relative degrees of curvature of the two lines reflect the differences set forth above: as safety effort is cut back (i.e., as the driver tries to speed up), the probability and/or cost of an accident rise more rapidly in the urban environment than in the rural one. Note that this difference of curvature relates specifically to the second degree partial derivative C_{ee} around the point of equilibrium: $C_{ee}^U > C_{ee}^R$, where the superscripts refer to urban and rural environments, respectively.

The effects of the differing sizes of the numerator and denominator terms in (6) work in the same direction: they both indicate that the motorist will exhibit less offsetting behavior in the urban environment than in the rural one. Analytically, it can be shown that if either C_{ee} is greater or C_{er} is less in an urban environment than counterparts in rural environments (or, most realistically, both inequalities hold), the offset will be greater (in numerical terms) in an urban environment than a rural

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evidence which provides some support for this view.

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one.[4] However, since the offset effect is negative, the fact

that it is a higher number in an urban environmnent than in a

rural one means that the negative effect is greater in a rural

environment.

Intuitively, it should be evident that the urban environment

offers the motorist fewer opportunities to substitute less safe

driving for safety devices than does the rural environment. This

lower level of opportunity for substitution is thus hypothesized

to generate a smaller offsetting response in the urban

environment.

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[4]Let OE^U be de/dr in an urban environment, OE^R be de/dr in a
rural environment. Then we have

$$OE^U - OE^R = [-C_{cr}^U / (C_{cc}^U + V_{cc})]$$

$$- [-C_{cr}^R / (C_{cc}^R + V_{cc})]$$

$$= [-C_{cr}^U (C_{cc}^R + V_{cc}) - (-C_{cr}^R (C_{cc}^U + V_{cc}))]$$

$$/ [(C_{cc}^U + V_{cc})(C_{cc}^R + V_{cc})]$$

$$= [C_{cr}^R C_{cc}^U - C_{cr}^U C_{cc}^R + V_{cc} (C_{cr}^R - C_{cr}^U)]$$

$$/ [(C_{cc}^U + V_{cc})(C_{cc}^R + V_{cc})]$$

By our earlier assumptions, the denominator to this last
equation is positive. Furthermore, we have also argued that from
our assumptions, the final term of the numerator, $V_{cc} (C_{cr}^R - C_{cr}^U)$, is
positive. Finally, regarding the first term of the numerator, note
that we have argued that $C_{cr}^R > C_{cr}^U$ and that $C_{cc}^U > C_{cc}^R$. If we
multiply these two inequalities (which we can do preserving the
direction of the inequality, since all terms are positive), we find
that the quantity in the numerator of the last equation above,
$C_{cr}^R C_{cc}^U - C_{cr}^U C_{cc}^R$, must be positive, as well. This proves our result
that the offsetting result in urban areas should be larger in
numerical terms than the offsetting effect in rural areas, or,
since both are negative, that the negative effect is greater in
rural areas than in urban ones.

While the offsetting effect in terms of effort could reasonably be expected to be greater in rural areas than in urban ones, the same result does not necessarily follow as relates to the outcomes of that effort in accidents and fatalities: more safety regulation does not necessarily lead to higher fatalities in rural environments than in urban ones. That is specifically because the relationship between effort and fatalities is different between the two environments, as discussed above. Nevertheless, it would seem evident that, if the urban environment reflected extreme situations such as bumper-to-bumper traffic, since the opportunities for offsetting behavior are practically nonexistent, the differences in effort could very well translate into differences in safety outcomes, as well.

The argument made here is analogous to the argument originally made by Peltzman regarding the offset hypothesis in a single environment, which is that higher levels safety regulation do not necessarily lead to higher fatality rates, but they can, and if higher rates are observed as a result of regulation, that is likely to be due to the offset effect. Similarly, the argument here is that while the offset effect does not necessarily generate greater increases in fatalities in rural environments than in cities, it can do so, and if the reverse effect of regulation on fatalities is stronger in rural environments than in urban ones, that is likely to be the result of the offset effect.

This analysis suggests some important things, both about testing offsetting behavior and about public policy. First, it suggests an empirical hypothesis: that if safety regulations seem less effective in achieving their purported goals in rural than in urban environments, that is likely to be evidence of offsetting behavior. Conversely, if this hypothesis is correct, it suggests that public policy which tries to save lives through regulations (including speed limits) could well be less effective in rural environments than in urban ones. Empirical tests for this hypothesis are developed and done below.

Further hypotheses. To test for the main hypotheses analyzed here, it will be necessary to control for other socioeconomic determinants of auto accidents, also allowing us to test the importance of other social policies on highway safety. As relates to more basic economic issues, a literature has developed in health economics asserting that individual, as well as regulatory variables, should have a strong effect on health and safety in many aspects of human life. One particular literature, with important contributions by Grossman (1972, 1975) argues that education levels should be closely (and very likely positively) related to levels of health and safety. Furthermore, Fuchs (1974), Grossman (1972), and Peltzman (1975) have asserted that there is likely a relationship between income on the one hand and health and safety on the other, though the direction of the relationship is ambiguous. This analysis affords tests of

hypotheses relating to the economic determinants of health and safety based on more extensive evidence than previous studies.

II. SPECIFICATION

It is first worth considering what form is theoretically appropriate for the estimating equation. As was previously stated, the process generating motor vehicle accidents is a complicated one, depending on personal, technological, and legal variables, and the equation estimated is an approximation for such a process. There are, however, some important and basic aspects of this process which do suggest a form for the equation specified.

Form of equation. The probability that a particular member of a population will be killed in an auto accident during a given period is (fortunately) low; there is a finite count of fatalities in a given population. In such general situations of regression with a small-count variable as dependent variable, a Poisson process best describes the dependent variable. In this situation, linear least squares does not appropriately characterize the equation or error term. Although Poisson regression is possible, a general regression of the following form is a realistic and practical approximation:[5]

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[5]Cook and Tauchen (1984), Hall, Hausman, and Griliches (1984), Rose (1988), and Kanafani and Keeler (1989, 1990).

$$Y_i = EXP(\; a_0 + \sum_j a_j \, X_{ij} + e_i) \qquad\qquad (7)$$

In this equation, the Y_i are observations on the dependent variable, X_{ij} is the i'th observation on the j'th independent variable intended to explain auto fatalities, and the e_i represent an econometric error term. This is algebraically equivalent to

$$Log(Y_i) = a_0 + \sum_j a_j \, X_{ij} + e_i \qquad\qquad (8)$$

making the equation suitable for linear estimation. Estimation will be discussed below, but first, it is appropriate to consider the appropriate variables to include in (8).

The dependent variable. Motor vehicle fatalities would itself seem an appropriate variable. However, it would also seem most sensible to standardize the dependent variable for the potential number of fatalities across counties. There are several ways of doing this, but the two most often used in previous studies are population (a measure of total potential drivers, passengers, and pedestrians who could die from accidents) and vehicle-miles (a measure of the amount of traffic). Both need to be taken account of. For our equation, we shall divide by population, but also use a variable measuring vehicle-miles per capita traveled as an independent variable, to be discussed below.

Regulatory and legal variables. Numerous policy variables

affect auto accidents, and we consider them now.

Two regulatory factors affecting highway safety are perhaps most controversial: auto safety device regulations and speed limit regulations.

The effects of auto safety device regulations (starting with mandatory seatbelts in the mid-1960's) have been studied extensively, starting with Peltzman (1975). We shall analyze their effects cross-sectionally by analyzing the extent to which variations in vintages of cars (with differing safety attributes for each vintage) across counties has an effect on fatalities. We shall consider effects of regulation for both 1970 and 1980 cross sections.

Also quite controversial is the effect of the speed limit on expressways and on rural non-limited-access roads. A number of students of this issue believe strongly that a lower speed limit reduces accidents and reduces fatalities (see, for example, Fowles and Loeb, 1989, Levy and Asch, 1989, and Snyder, 1989). Another group, most especially Lave (1985, 1989) and McCarthy (1988) believes that within the range of speed limits currently available or under consideration (55-65 miles per hour) there is little or no relationship. They believe that it is the variance of speed on the road, rather than the speed itself, that affects accidents and fatalities.

Most previous studies have used the observed speed on rural roads as an exogenous variable here, and possibly the variance in

speed, as well. But observed speed is not an exogenous variable from the viewpoint of public policy. And indeed, because enforcement can never be perfect, the actual speed cannot be a truly exogenous variable from the viewpoint of public policy. As a result, the present study analyzes the effects not of speed itself, but of publicly-imposed speed limits. Our focus will be on maximum speed possible on expressways and rural roads, since that is the object of the most controversy (use of a population density variable will control for situations in which urbanized counties have little opportunity to use the maximum speed, as will stratification of the sample into high-density and low-density components).

There are other important regulatory variables affecting motor-vehicle safety. The existence of a state vehicle inspection program has been found by previous studies to have an effect, as has more frequent license renewal testing. Yet another set of regulatory variables relates to alcohol. States control availability and price of alcohol, through taxes, licensing restrictions, price regulations, hours of sale, minimum drinking ages, and, in some cases, prohibition on the sale and consumption of alcoholic beverages. Minimum drinking age is controlled at the state level, and data on it is readily available, so it is included in the equations as a variable, county by county (0 if the drinking age was 21 and 1 if it was lower).

Another appropriate variable would be the real price of alcoholic beverages, especially those known to be associated with motor accidents, namely beer. Real beer price data, however, are not available cross-sectionally at the county level, nor are data on alcohol consumption. Per capita consumption data are available, however, at the state level, and it is appropriate (at least to control for the effects of alcohol consumption in measuring the effects of other variables) to include average per capita alcohol consumption as a variable for each county. Initial work with the data indicated that total alcohol consumption is a better explanatory variable than is beer consumption, and that is the variable used.

Personal and economic variables. Previous analysts in the economics of health and safety have noted that income can have a positive or negative effect on safety (Fuchs, 1974, Peltzman, 1975). Higher income implies, on the one hand, that the consumer can afford to invest in things which improve safety (such as safer cars, and may also have access to superior health care in the event of injury from an accident).

On the other hand, in the area of driving, higher income can also mean more risky behavior: faster cars, and possibly (as pointed out by Peltzman, 1975) taking more chances in driving. In any event, income would appear to be an important variable for inclusion.

Another demand variable which is important is something to

measure the amount of driving done. Typically, the variable used is vehicle-miles traveled. This variable is not available at the county level, but another variable, closely-related to vehicle use, is available: retail sales of highway vehicle fuel. As will be seen, this would seem to be a very accurate proxy for vehicle-miles traveled.

Another personal variable which economists have found to be important in explaining behavior with respect to health and safety is education. The work of Grossman (1972, 1975) has shown theoretically that education is likely to have a positive effects on health-promoting behavior, and there is evidence in many areas that this is in fact true. (See, for example, Farrell and Fuchs, 1982). Indeed, Fuchs (1982) has found that people with higher levels of education are more likely to use seat belts, and Fuchs and Leveson (1967) have found some direct evidence of a relationship here, also.

From this previous work, it is clear that education levels are an important potential variable for explaining motor-vehicle accidents, and but no previous study of the determinants of motor vehicle safety has included education variables (with the exception of the work of Fuchs and Leveson, 1967, which was based on a small data set and did not consider a number of other important variables). The present study includes two education variables: the per cent of the population over 25 with high school and college educations, respectively.

Another personal, demographic variable which is relevant to motor vehicle accidents is the per cent of the population made up of young people, who have a higher accident rate than other age groups in the population. Specifically, young men have accident rates higher than other parts of the population.[6] So I also include a variable indicating the percent of the population made up of males aged 15-24.

Finally, the per cent of the population which is elderly can have an effect on auto fatalities, as well. Although the ability of the elderly to drive is perhaps weakened by reduced vision and slower reflexes, the elderly are also known to be extremely cautious drivers, so that recent work argues they are both theoretically and empirically likely to behave more safely than middle-aged drivers. In any event, we include in our equations variables for the per cent of the population over the age of 65.

Technological and other variables. Quick availability of emergency medical care is likely to have a strong impact on ability to save lives in the event of auto accidents, and as a result, the distance of the nearest hospital is likely to be important. So I include a variable for hospitals in the equation. A priori, it would seem that the proximity of one hospital in a given area would have a strong effect, but that the incremental effect of many hospitals in an area would be weaker,

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[6]See, for example, Cook and Tauchen, 1984.

and evidence confirmed this to be the case. As a result, I have included a simple zero-one variable, equal to zero if there are no hospitals in the county, and one otherwise.

Population density is likely to affect fatality rates, because high densities imply a type of driving (frequent stops) which should, all other things equal, reduce the likelihood of fatal accidents. Therefore, in addition to stratifying by this, I include it as a variable.

III. Estimation and Data

This section considers appropriate techniques for estimation of (8), as well as summarizing the available sources for the data.

Estimation. Equation (8) represents an appropriate form for estimation, but, even here, the error term is not consistent with the assumptions of ordinary least squares. To correct for this problem, we use a solution recommended by Cook and Tauchen (1984), who note that with a lognormal approximation to the Poisson distribution, the variance of the error term in (8) has the following relationship to the size of the county (or other population) observed:

$$\sigma^2 = b_0 + \log [1 + (b_1/POP] \tag{9}$$

where POP is the population of the relevant state (in Cook and Tauchen's case) or county.

Given this, the appropriate econometric procedure is two-step, generalized least squares. First, estimate (8) using ordinary least squares. Second, estimate (9) using nonlinear least squares, using the squared residuals from the first-round equation as estimates of σ^2. Third, use weighted least squares to re-estimate (8), using as weights reciprocal of the square root of the predicted value of σ^2 from (9). That is the estimation procedure used here (results for both ordinary least squares and generalized least squares are reported).

One other estimation problem must be considered. Some counties have zero fatalities, and, in this case, taking the logarithm of the dependent variable is impossible. One solution, suggested by Pakes and Griliches (1980) is, when the dependent variable is zero, to set it equal to one (so that the log is zero), but then to include a dummy variable as an independent variable, equal to one of the dependent variable is zero. In this way, the specification is preserved, but zero values of the dependent variable are accounted for.

Data. All the data for this study have been collected at the county level for the U. S. A., excluding Alaska (because the roads there are so dramatically different from elsewhere; also, Oklahoma was excluded, because it does not report the automobile registration data needed for the regulation variable). This

affords a total of 3,030 observations for the United States for 1970, and 2,658 for 1980.[7]   Sources for all the data used are reported in Table 1.

As previously stated, the years 1970 and 1980 were selected: census data exist for both times, and both years provide useful, separate information; 1970 us useful because at that time, there was wide variation in speed limits across states, and thus data for that year afford rich opportunities for testing the effects of speed limits on fatalities. Also, at that time, there was significant variation across states in minimum drinking age,[8] and there is reason to believe that that, too, has some effect on fatalities. 1980 is of interest because minimum drinking age was at maximum variation, allowing for tests of the hypothesis that it mattered. Finally, in both years, auto regulation was important, but it was much milder in 1970 than in 1980, including mainly safety belts with shoulder harnesses for recent-model cars. By 1980, however, regulation was much stronger, requiring, among other things, high-impact bumpers, collapsable steering columns, and extra-strength doors. Each year affords the

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[7]For 1980, some counties did not report retail gasoline sales, and they were necessarily excluded in that year. Also, the boroughs of New York City have been excluded for both years, because separate fatality data are not available for them.

[8]It was not, however, until well into the 1970's that minimum drinking age under 21 reached its widest range among states. This fact is discussed further below.

opportunity to test important hypotheses about effects of
regulation.

In addition, the data for each year were stratified into two
sets, on the basis of population density. This was, first,
strongly justified on a statistical basis: for 1970, for
example, it was possible to reject the hypothesis that the two
data sets had the same regression coefficients at the .001
level.[9] But the reasons for this should also be evident on an a
priori basis: we have already discussed the reasons why
offsetting behavior might be expected to be stronger on rural
roads than urban ones; furthermore, many believe that a high
speed limit may be safe in low-density areas, but not in heavily-
populated ones. Indeed, it makes sense that all variables should
be given the opportunity to have different effects in high- and
low-density counties, and, since stratification into two groups
still affords over 1,200 observations per group in both periods,
very little is sacrificed in terms of a large statistical sample
by doing this, either.[10]

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[9]The relevant test statistic (comparing sums of squared
residuals for pooled and unpooled ordinary least squares
equations) for 1970 is $F = 16.2$, which indicates a difference at
the 1 per cent level.

[10]Another approach, which would arguably allow for both
pooling of data and for differences where coefficients do differ,
would be to pool both data sets, but to allow for different
intercept variables between the samples, as well as different
slopes for those variables for which slopes appear to differ.
The difficulty with this approach is that it is rather arbitrary
as to which slopes should be allowed to differ. In any event,
the results shown in Tables 2 and 3 are quite robust to use of

Table 1 shows the variables included in the equations. To get a sense of the densities involved, it is worth noting (for example) that the mean population density in the "low-density" 1970 sample is 14.8 people per square mile. A county such as this one is a rural one, but one with well-developed small cities and towns and agriculture. Examples of these counties may be found in most parts of the U. S., including agricultural parts of the Northeast (Potter County, Pennsylvania), the South (Van Buren County Tennessee), the Midwest (Chariton County Missouri), and more settled (but still rural) areas of the West (Mendocino County, California).

The mean population density of the high-density sample is 360.6 for 1970. This is the sort of density found in counties with larger cities and some rural land, as well. Examples would be Kalamazoo County, Michigan and El Paso County, Texas. These examples are given to be suggestive of the sorts of mean densities for which the results are most relevant, though density is itself a variable in the equations, as well.

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this procedure. Specifically, for 1970, when the two samples were pooled, with different constants and different slope coefficients for income, high school education, and speed limits, the qualitative results were identical to those shown in Tables 2 and 3, with the sole exception that the alcohol-related variables, alcohol consumed and minimum drinking age, became more statistically significant. The alcohol variable became significant at the 15 per cent level. While this is not highly significant, it nevertheless suggests what other studies have shown: with a data sample geared to studying the effects of alcohol on traffic fatalities, the results would show a meaningful effect.

IV. Results

The results of the equations are shown in Table 2 (for 1970) and Table 3 (for 1980). They are revealing in several ways.

First, the results relating to regulation are supportive of our hypotheses about offsetting behavior: in every case but the urban areas in 1970, the coefficient has a negative sign, implying that counties with older, less-regulated vehicles had fewer accidents, controlling for vehicle utilization. Furthermore, in both years, our hypothesis about the place in which offsetting behavior should happen more strongly is also correct: it is in the rural areas that the effect appears to exist exclusively in 1970, and in 1980, though the effect seems present in both urban and rural environments, it is stronger in rural areas, in terms both of the size and the significance of the coefficients.

Second, as relates to the speed limit, the evidence for 1970 (the only year with variations in speed limits on expressways), indicates strongly that that regulation has its intended effect only in urban areas. In rural areas, there is no evidence of any reduction in fatalities from lower speed limits. This result is possibly due to any one (or a combination) of three effects: first, as we have previously pointed out, offsetting behavior can reduce the effect of a speed limit, and that is much more

feasible in rural than in urban environments. Second, evasion of

speed limits may be easier in rural environments. Third, it is

possible that it is the variance of speeds that causes

fatalaties, as hypothesized by Lave (1985), and one would expect

the variance effect to be weaker in uncongested situations than

in congested ones.

The coefficients for income are more consistent with

Peltzman's hypotheses than in previous studies, in that Peltzman

argued that higher levels of income could as easily increase

fatalities as reduce them: income increases the demand for safe

vehicles, but it also increases the value of fast driving.

Previous studies consistently find a strong negative effect of

income on fatalities, while the results here reflect the

ambiguities set forth by Peltzman: In urban areas, income has a

negative effect on fatalities. However, in low-density areas,

the effect is insignificant or even positive. This result is

consistent with our earlier argument, that more intensive driving

is mainly feasible in rural areas. So the tendency to drive

faster with higher incomes seems to manifest itself in rural

areas, in which opportunities to drive in this way are perhaps

greater.

The effects of education are as expected: more education

(especially college) and higher income appear to consistently

increase safety. The education component is strongly consistent

with Grossman's and others' hypothesis about the relationship

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between education and the demand for safety.

Among the technological effects, vehicle-miles traveled (proxied by fuel consumption) have a strong effect as expected in almost all equations, as does population density (which results in lower fatalities, all other things equal).

Many of the other social and regulatory variables have a stronger effect in urban than in rural areas, perhaps because their effects are increased by congestion.

Minimum drinking age has little effect, with the important exception of in high-density counties in 1980, when the most states had low minimum drinking ages (that is the case in which the expected effect would be strongest). Alcohol consumption has a weak effect, though in 1980 it is positive and marginally significant.

Longer license renewal periods do indeed reduce safety-- license testing, like education, seems to have a strong effect, with no offsetting. The same cannot be said of vehicle- inspection programs. The sign is consistently the opposite of what is expected. Offsetting behavior may be possible here.

Elderly drivers appear to have a lower fatality rate than others, an effect predicted by the theoretical analysis of Erlich and Chuma (1990). On the other hand, the results relating to male youth are contrary to what many believe, though they are consistent with the cross-section results of Peltzman (1975).

Heavy trucks are if anything safer than private autos,

attesting to the professional drivers these vehicles tend to
have. But light trucks tend to be less safe than cars, perhaps
because of the driving habits of drivers of these vehicles.
These results could also be taken to be supportive of the
hypothesis that safety-device regulation reduces fatalies,
because these vehicles were not required to have safety devices
for the periods under consideration.

V.   Conclusions

The results of this paper provide several important
conclusions regarding economic aspects of highway safety. First,
they provide strong evidence supporting the controversial offset
hypothesis initiated by Peltzman. It does so not only because of
the sign of the regulation variables in the cross-section
equation, but also because of the relative values and
significance levels of these variables for high-density and low-
density situations. Furthermore, the paper gives strong evidence
that, at least as of 1970, when speed limits varied widely, lower
rural speed limits had no effect by way of reducing fatalities.
This is likely due to either the offsetting effect, or to its
close relative, evasion. Similarly, vehicle inspection programs
have no effect on safety. Evidence for 1980, a year the number
of states permitting drinking by those under 21 was at a peak,
indicates that higher minimum drinking ages do have an effect of

reducing fatalities.

As relates to income and education, the theoretical model indicates that the effect of income on safety is ambiguous, and our results are consistent with that. In high-density environments, income has a positive effect on safety, but it is ambiguous and of weak significance in rural environments, in which drivers are most likely to reflect higher values of time by driving faster. The effect of education on safety is consistently positive, and it suggests that the returns to education go well beyond additional earning power. It also suggests that the relation between education and health, first found by Grossman and confirmed by Fuchs, is further confirmed here.

While the main purpose of this research is to test basic economic hypotheses about highway safety behavior, neverthless, there are some clear implications for public policy. First, because there is significant evidence of offsetting behavior, regulations requiring safety devices in cars may be weaker in effect than intended, and can even have effects opposite those intended, especially in lower-density environments.[11] Second, it

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[11]It is worth noting, however, that even if safety regulations have the opposite effect of that intended, they still give value to consumers. The value will occur either in the form of greater safety or greater speed, or some combination. Of course, whether these consumer benefits are great enough to equal or exceed the extra costs of manufacture for safer cars is a separate question, beyond the topic of this paper. For estimates, see Crandall, et. al., 1986.

would seem clear from the 1970 results that a speed limit of 55 miles per hour on low-density rural highways has little if any salutory effect on safety. On the other hand, for more congested roads in higher-density environments, a 55-mile-per-hour speed limit can be an effective way of avoiding fatalities. This would suggest that the recent change in the United States, of allowing speed limits of up to 65 miles per hour on uncongested rural expressways, should cause little overall harm to safety.

Some other policies, such as vehicle inspection programs, seem also to be of little use in improving safety. On the other hand, yet other policies, such as frequent testing for license renewals appears to have the desired salutory effect.

If there are two unifying themes to this analysis, they are (1) that the consumer-theoretic model of driver safety behavior has considerable validity and (2) that responses to regulatory policies are likely to differ considerably, depending on driving environment.

Table 1. Variables used in empirical analysis

Variable	Definition (source)
Fatalities/ Per Capita	Fatalities per 1,000 population[a]
Alcohol gallons[b]	Total consumption of alcohol per capita,
College	Per cent of population over 25 having completed college[c]
Gasoline/capita	Retail gasoline sales (dollars) per capita[d]
Heavy Truck	Per cent vehicle-miles in state accounted for by heavy trucks[g]
Hospital	Discrete variable equal to one of there is a hospital in the county, zero otherwise[c]
Income	Income per capita, thousands of dollars[c]
Inspection Program	Discrete variable, equal to one of state has a vehicle safety inspection program, zero otherwise[f]
License Ren. Period	Period (in years) between license renewals[g]
Light Truck	Per cent of vehicle-miles in state accounted for by light trucks[g]
Minimum Age	Minimum drinking age[h]
Elderly	Per cent of population over 65[c]
High School	Per cent of population over 25 with high school diploma[c]
Male Youth	Per cent of population consisting of males 18-24[c]
Population Density	Population per square mile[c]

Table 1. Variables used in empirical analysis (continued)

Variable	Definition (source)
Regulation	A variable between zero and one, intended to reflect relative safety levels of statewide fleets. A value of 1 reflects safety levels of pre-1966 vehicles; a value of .6 reflects NHTSA's estimate of the relative safety of a post-1975 vehicle. Values for a county reflect statewide fleet averages, based on relative estimated vehicle-miles for each vintage car.[j]
Speed Limit	Maximum speed permitted on rural highways in 1970 (not used in 1980 equation)[i]

[a]Fatality data are from U. S. Department of Health and Human Services, Public Health Service, Vital Statistics of the United States, 1970, Vol. II, Part B: Mortality, pp. 7-693. For population data, c. f. c, below.

[b]U. S. Brewers' Association, The Brewing Industry in the United States, Brewers' Almanac, 1973.

[c]U. S. Bureau of the Census, 1970 Census of Population.

[d]These figures are for 1972, and are from U. S. Bureau of the Census, 1972 Census of Business.

[e]"Hospitals," Journal of the American Hospital Association 44 (August 1, 1970), pp. 16-238.

[f]Callahan (1970).

[g]U. S. Bureau of Public Roads, Highway Statistics, 1970, 40.

[h]Cook and Tauchen (1984), pp. 187-188.

[i]Rand McNally Road Atlas, 1970.

[j]The variable used here for both 1970 and 1980 is originally based on calculations of Graham (1983): a safety regulation variable based on the relative (technologically-expected) safety levels of each vintage of auto, as estimated by the U. S. Department of Transportation Fatal Accident Reporting System database. Thus, a pre-1965 car has a value of 1, but an auto from the late 1970's had a value of .6. Values of this variable were calculated for each state, and each state's value was applied to counties within the state. The value for each state was calculated by finding the number of vehicles for each vintage of the previous 10 years, and estimating the vehicle-miles each vintage contributed to the total, based on U. S. Department of Transportation estimates of utilization for each vintage over a car's ten-year life. The formula for calculation of the safety variable is therefore (for each state i, with t = 1,...,10 vintages)

$$\text{REGULATION} = \sum_t s_{it} R_t$$

where s_i is the share of each vintage t in vehicle-miles traveled, and R is the regulation-related safety level (less than or equal to one) of vehicles in that vintage.

Table 2. Statistical Results for 1970 (T-Statistics below estimates)

| Variable | Low Density | | High Density | |
	OLS	GLS	OLS	GLS
Constant	3.86367	2.31389	-0.45273	0.57780
	(1.00846)	(0.60586)	(-0.12270)	(-0.17651)
Alcohol	-0.00617	0.00432	-0.01264	-0.00989
	(-0.10308)	(0.07183)	(-0.28201)	(-0.25553)
College	-0.00437	-0.00757	-0.01330	-0.01284
	(-0.58184)	(-0.99093)	(-3.09949)	(-3.30157)
Discrete-Zero	7.57810	7.63196	8.03341	8.02440
	(125.60480)	(119.77858)	(39.76840)	(27.81487)
Gasoline/Capita	0.30180	0.36247	0.61835	0.92600
	(9.81888)	(8.11180)	(3.63739)	(5.00013)
Heavy Truck	0.00533	0.00515	-0.00165	0.00278
	(0.63297)	(0.61379)	(-0.24432)	(0.45969)
Hospital	-0.04442	-0.01809	-0.05221	-0.03216
	(-1.21945)	(-0.49497)	(-1.39541)	(-0.77885)
Income	-0.00004	-0.00006	-0.00008	-0.00011
	(-0.95264)	(-1.46579)	(-2.05969)	(-3.03202)
Inspection Program	-0.02292	-0.02666	0.02149	0.01542
	(-0.54620)	(-0.63993)	(0.74130)	(0.57465)
License Ren. Period	-0.00051	0.00278	0.02342	0.03309
	(-0.03002)	(0.16423)	(1.87625)	(2.78053)
Light Truck	0.00129	0.00169	0.00298	0.00416
	(0.32740)	(0.43665)	(0.98298)	(1.52167)
Minimum Age	0.01508	0.01566	0.00330	-0.00115
	(1.09745)	(1.15551)	(0.36395)	(-0.13970)
Elderly	-0.01428	-0.01514	0.00713	-0.00444
	(-3.16799)	(-3.32914)	(1.66583)	(-2.55973)
High School	0.00009	0.00010	-0.00417	-0.00599
	(0.43047)	(0.51223)	(-2.21580)	(-1.51449)

Table 2. Statistical Results for 1970 (Continued; T-Statistics below estimates)

Variable	Low Density OLS	GLS	High Density OLS	GLS
Male Youth	-0.03723 (-3.05315)	-0.03513 (-2.90007)	-0.00235 (-0.58772)	-0.00045 (-0.11887)
Population Density	-0.01330 (-6.51956)	-0.01193 (-5.92319)	-0.00005 (-7.71748)	-0.00005 (-9.64645)
Regulation	-12.32191 (-2.80992)	-10.48561 (-2.40086)	-8.76586 (-2.12925)	-8.50160 (-2.32965)
Speed Limit	0.00008 (0.01651)	-0.00209 (-0.43642)	0.00821 (2.96979)	0.00635 (2.67082)
Adjusted R^2	0.92619	0.93124	0.56341	0.95012

Table 3. Statistical Results, 1980 (T-Statistics are below estimates)

Variable	Low Density		High Density	
	OLS	GLS	OLS	GLS
Constant	-0.31726	-0.29863	-2.71786	-0.82156
	(-0.07101)	(-0.06667)	(-0.24707)	(-0.07849)
Alcohol	0.06704	0.06656	0.03876	0.03839
	(1.82880)	(1.81623)	(1.23002)	(1.30970)
College	-0.00627	-0.00630	-0.01443	-0.01517
	(-1.14495)	(-1.14805)	(-4.16409)	(-4.59225)
Discrete- Zero	7.86134	7.86523	8.28176	8.31202
	(124.12471)	(123.33480)	(44.62717)	(29.22131)
Gasoline/ Capita	0.06394	0.06464	0.09377	0.08863
	(1.73316)	(1.74353)	(1.53473)	(1.34213)
Heavy Truck	0.00122	0.00088	-0.02665	-0.02820
	(0.14586)	(0.10501)	(-3.53381)	(-3.92161)
Hospital	-0.06364	-0.06249	-0.03925	-0.04627
	(-1.55482)	(-1.52299)	(-0.82009)	(-0.87120)
Income	0.00001	0.00001	-0.00001	-0.00002
	(1.10235)	(1.13811)	(-1.08236)	(-1.80684)
Inspection Program	0.11301	0.11307	-0.02722	-0.02909
	(3.00997)	(3.01297)	(-0.83376)	(-0.93038)
License Ren. Period	-0.00571	-0.00553	0.05659	0.06130
	(-0.24843)	(-0.24076)	(3.49153)	(3.89980)
Light Truck	0.00548	0.00553	0.01379	0.01462
	(1.52470)	(1.54008)	(3.67774)	(4.19565)
Minimum Age	0.00751	0.00746	-0.02677	-0.02746
	(0.52750)	(0.52366)	(-2.28420)	(-2.48087)
Elderly	-0.00366	-0.00369	-0.00311	-0.00208
	(-1.79923)	(-1.80984)	(-1.58544)	(-1.07810)
High School	-0.01246	-0.01242	-0.00314	-0.00564
	(-1.23517)	(-1.23177)	(-0.50913)	(-0.92170)

Table 3.   Statistical Results, 1980   (Continued; T-Statistics are below estimates)

Variable	Low Density		High Density	
	OLS	GLS	OLS	GLS
Male Youth	-0.00888 (-5.81499)	-0.00883 (-5.78175)	-0.00001 (-1.19731)	-0.00000 (-0.88191)
Population Density	-11.01934 (-1.65390)	-11.04807 (- 1.65383)	-7.42328 (-0.45785)	-10.17770 (-0.65969)
Regulation	-0.01286 (-2.88587)	-0.01285 (-2.88351)	0.00248 (0.59721)	0.00106 (0.26540)
Adjusted R-Squared	0.92952	0.92975	0.63399	0.90556

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Figure 1. The trade-off between safety effort and accident cost
in urban and rural environments
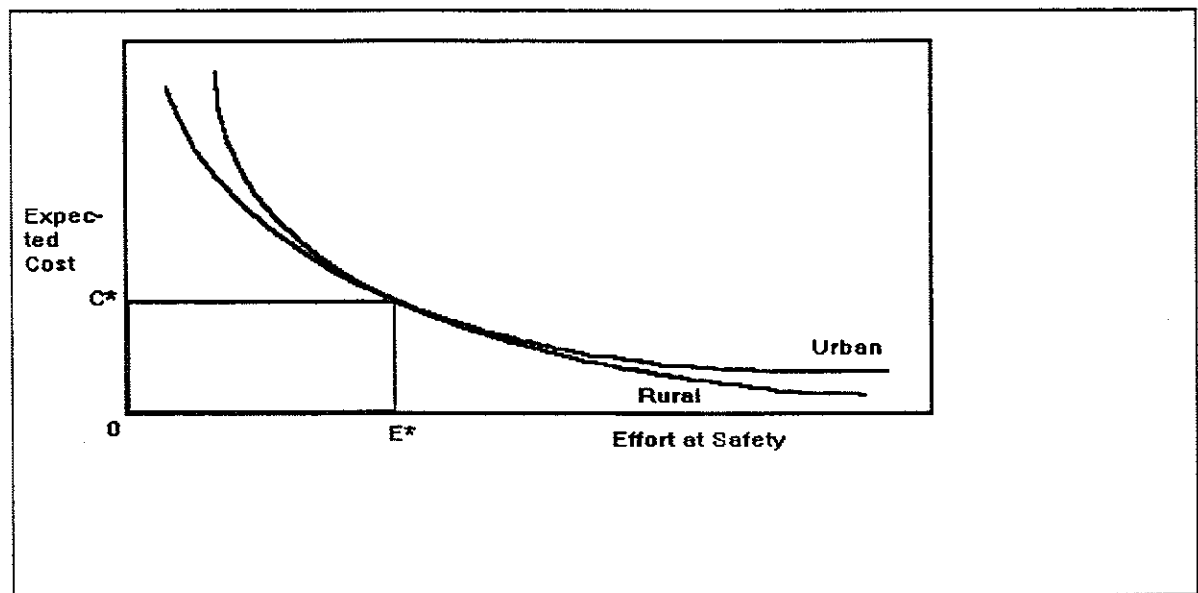
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