# Car Mass and Fatality Risk: Has the Relationship Changed?


## ABSTRACT

*Objectives.* The finding that the relative safety disadvantage of small compared with large cars is less for post-1980 cars than for pre-1980 cars has stimulated speculation that increasing fuel economy standards would increase fatalities less than previously expected. Fatal crashes between two cars of similar model year were examined to see whether this would be the case.

*Methods.* Driver fatality risk in relation to car mass was examined with Fatal Accident Reporting System data for crashes between two cars of a specific model year.

*Results.* The relative risk for driver fatality in the lighter car compared with the other driver's risk in a car 50% heavier was as follows: for 1966 through 1979 cars, the risk was between 3.7 and 5.1; for 1984 cars, 2.6; and for 1990 cars, 4.1.

*Conclusions.* The results suggest that the lesser mass effect observed for mid-1980s cars occurred because improved crashworthiness features appeared in small cars earlier than in large cars. As all cars are redesigned, the relationship between risk and mass can be expected to approach that observed earlier in pre-1980 cars. If so, future fatality increases from fuel economy increases will be greater than estimated on the basis of mid-1980 data. (*Am J Public Health.* 1994;84:33–36)



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## Introduction

It has been established for decades that when cars of unequal mass crash into each other, driver fatality risk in the lighter car exceeds that in the heavier car.[1] Recent studies have found that the difference in fatality risk for the same mass difference is greater for older cars (model year 1979 or earlier) than for more recent cars (1980 or later).[2–4] Such findings have contributed to suggestions that car mass is exercising a declining effect on fatality risk and that car mass effects on safety might become less important or even disappear in the future. Such suggestions imply that increasing fuel economy standards would lead to a smaller increase in occupant fatalities than would be expected on the basis of current or earlier data.

The purpose of the present study was to determine whether the relationship between driver fatality risk and car mass has changed and to identify the relationship most likely to apply in the future. We used data from crashes between two cars of unequal mass but similar model year to determine how the ratio of drivers killed in lighter cars to those killed in heavier cars depends on the ratio of the masses of the cars.

## Methods

The Fatal Accident Reporting System is a computerized data file maintained by the National Highway Traffic Safety Administration that contains detailed information on all fatal traffic crashes in the United States since January 1, 1975.[5] We used data for two-car crashes between 1975 and 1991 in which at least one of the two drivers was killed and for which the mass and model year of each car were coded.

The method was identical to that used in our previous study,[2] except that the analysis was confined to crashes between cars of specific model year. Ideally, we would have liked to focus exclusively on crashes between cars of the same model year; however, there are generally insufficient data to allow such analyses. Instead, we used a moving average approach that includes cars of the previous and subsequent model years. For example, we include any crash between a 1974, 1975, or 1976 model year car and any other 1974, 1975, or 1976 model year car, thereby increasing the expected number of crashes by a factor of nine. The central value of the moving average—in this example, model year 1975—is the independent variable in the analyses.

For each car crash, a mass ratio, $\mu'$, was defined as

$$(1) \qquad \mu' = \frac{\text{Mass of Heavier Car}}{\text{Mass of Lighter Car}}.$$

All crashes for each model year were divided into five categories of $\mu'$; as far as possible, the five categories contained equal numbers of crashes. For each category, a driver fatality ratio, $R$, was defined as

$$(2) \quad R = \frac{\text{No. Driver Fatalities in Lighter Cars}}{\text{No. Driver Fatalities in Heavier Cars}}.$$

The data were least squares fitted to

$$(3) \qquad \log(R) = u \log(\mu),$$


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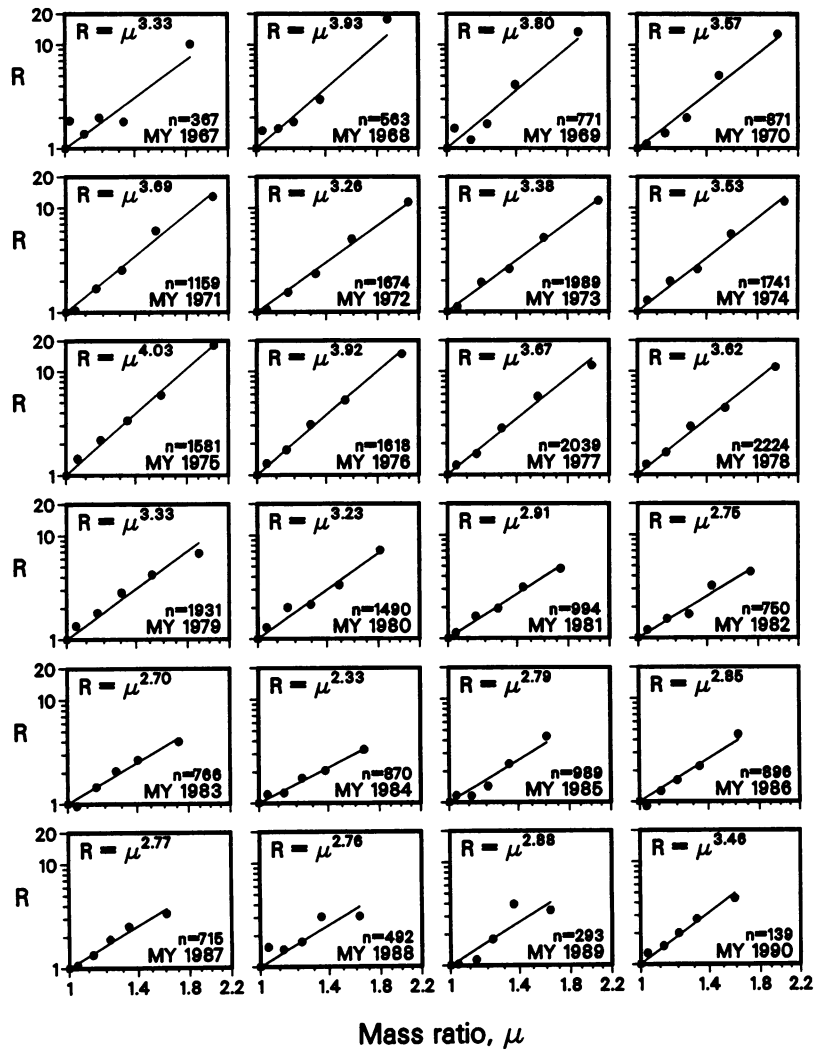


*Note.* The graph for model year (MY) 1967 includes all crashes in which a 1966, 1967, or 1968 car crashed into a 1966, 1967, or 1968 car, and so forth. The number of crashes contributing to each plot is indicated by n.

**FIGURE 1—Driver fatalities in the lighter car divided by those in the heavier car (*R*) vs the mass of the heavier car divided by the mass of the lighter car (μ).**

where μ is the average of the individual values of μ′ in the given category. Each point was weighted in inverse proportion to the variance, $\sigma^2$, in log(*R*). On the assumption that the fatalities arise from a Poisson process, this variance is given by

$$(4)\quad \sigma^2 = 1/(\text{Fatalities in Lighter Car}) + 1/(\text{Fatalities in Heavier Car}).$$

Because $R \equiv 1$ when $\mu = 1$, the fit involves only one parameter, *u*; crashes between cars of equal mass are excluded from the analyses. Although the fit is to the log-transformed data, a more convenient form of Equation 3 is

$$(5)\quad R = \mu^u.$$

## *Results*

There are relatively few data for the early model years, because by the time the Fatal Accident Reporting System was begun in 1975, most such cars had already been retired from the road. For the most recent model years there are also relatively few data, because, for example, 1990 cars can contribute only to the data for 1989, 1990, and 1991. It will be another 10 or so years before nearly all crashes involving 1990 cars have occurred.

Because of the moving average approach, the results for specific model years are not independent of the data for adjacent model years. For example, the 1581 crashes for model year 1975 arise from the following specific contributions: (4,4) 225; (4,5) 308; (4,6) 386; (5,5) 137; (5,6) 318; and (6,6) 207 crashes, where (4,4) denotes crashes between model year 1974 cars and model year 1974 cars, and so forth. About 176 crashes (1581/9) are expected between cars of the same model year, and 704 between cars whose model years differed by one. Some of these same crashes also contribute to the estimates for model years 1973, 1974, 1976, and 1977. The error in *u*, Δ*u*, is one standard error.

Because Equation 5 contains only one parameter, *u*, the relationship it describes is determined completely by choosing any one illustrative point, such as, say, the one corresponding to one of the cars being 50% heavier than the other ($\mu = 1.5$). This provides a possibly more immediately understandable measure than the essentially equivalent parameter *u*. For example, for model year 1975 we obtain $R = (1.5)^{4.03} = 5.1$, meaning that if two 1975 cars, one of them weighing 900 kg and the other 1350 kg, crash into each other, the driver of the 900-kg car is 5.1 times as likely to be killed as is the driver of the 1350-kg car. The illustrative mass ratio of 1.5 rather than the value 2 used in earlier work[1,2] was chosen because very few cars made after model year 1980 had as much as twice the mass of other cars of the same model year.

Figure 1 shows *R* vs μ, as determined by dividing the data into five categories of mass ratio, leading to five plotted points for every model year. The choice of five was based on a compromise between the need to have a sufficient number of crashes in each cell for model years for which there were few data and the need for a sufficient number of points to accurately determine Equation 1. Although a case can be made for letting the number of categories increase for model years with more data, we considered it more important to subject the data for each model year to identical treatment. When there are many data, the estimated values of *u* and Δ*u* depend hardly at all on the number of categories, in accord with statistical theory. When there are few data and noisy relationships, the parameters are more dependent on the number of categories.

Because the parameters for model years 1989 and 1990, which are based on relatively few data, are central to the study, it is important to establish that they do not depend unduly on the arbitrarily chosen number of analysis categories. Using 3, 4, 5, 6, 7, 8, and 9 categories gives values of *u* for model year 1989 of 3.04, 3.04, 2.88, 2.76, 2.78, 2.92, and 2.90, re-

spectively; the corresponding values for model year 1990 are 3.17, 3.47, 3.46, 3.26, 3.17, 3.10, and 3.05 (the values used are underlined).

The variation of the parameter $u$ as a function of model year (Figure 2) indicates substantial changes. Of particular note is the strictly monotonic decline from $u = 4.03$ for model year 1975 to $u = 2.33$ for model year 1984. This decline is followed by a rapid rise to $u = 3.46$ by model year 1990. The upward trend indicates that the effect of mass on relative driver fatality risk for future model years may become similar to what it was for earlier model years.

The results above are for all drivers, regardless of safety-belt use. To address whether this fact might introduce confounding effects because safety-belt-use rates have increased, we repeated all analyses, excluding all drivers coded as using safety belts. The results showed no systematic departures from those shown in Figures 1 and 2. However, scatter increased considerably because of smaller sample sizes; the total number of available crashes for model years 1984 through 1990 decreased by more than 50%. Such large reductions occur because if either driver is coded as belted, the crash is excluded. After laws requiring safety-belt use became widespread, nonwearers, especially surviving drivers, were increasingly likely to be incorrectly coded as wearers.[1]

The decision to include drivers regardless of safety-belt use is not expected to have had much effect on the pattern shown in Figure 2. A number of studies using a variety of methodologies have indicated that safety-belt effectiveness does not depend systematically on car mass.[1,2] The study that most closely parallels the present one found a value of $u$ in Equation 5 for unbelted drivers of 3.58, compared with $u = 3.53$ for drivers regardless of belt use and $u = 3.60$ for belted drivers.[2] Even if belt-wearing rates did depend on car mass, this would not affect results much because belt use was relatively low for all model years (27% of fatally injured drivers for model year 1987 were coded as belted, the highest rate for any model year) and belt effectiveness is lower in two-car crashes (30% ± 8%) than in single-car crashes (62% ± 5%).[6] Additional analysis found no important relationships between belt-wearing rates and car mass for any model year.

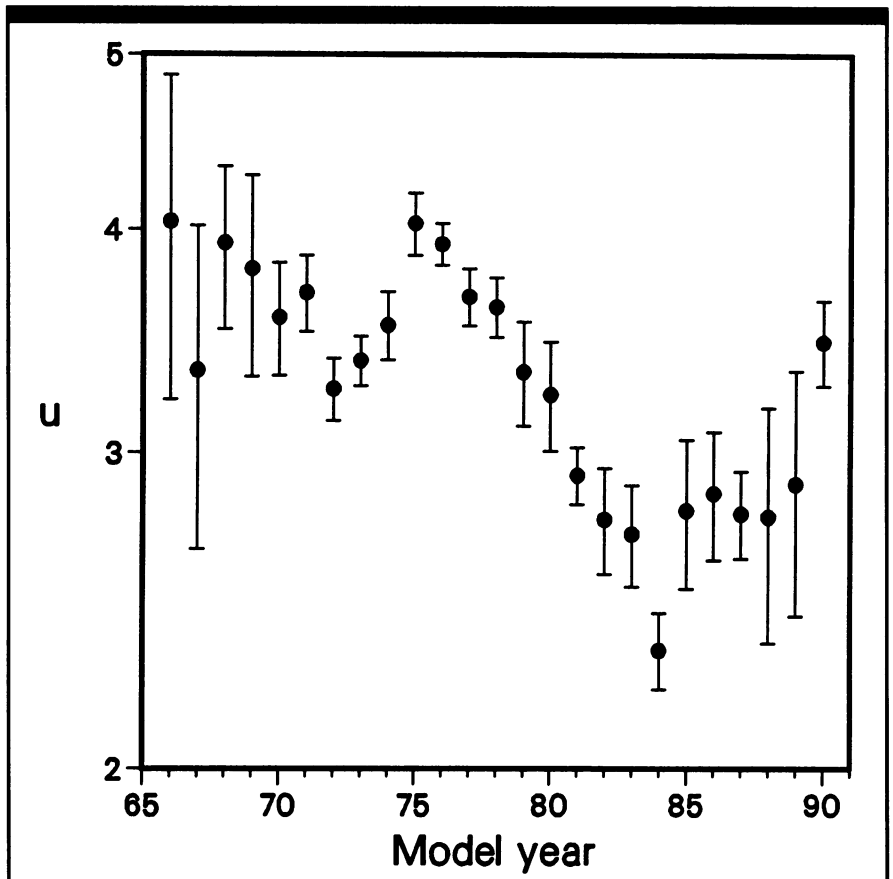


**FIGURE 2—The parameter $u$ in the relationship $R = \mu^u$, by car model year.**

## Discussion

The main purpose of a phenomenological study like the present one is to discover what is happening. Although the results of such studies do not identify the mechanisms leading to the observed effects, they may offer insights into such mechanisms. The following interpretation of Figure 2 is offered as a plausible, though not demonstrated, explanation.

One can interpret a relationship between car mass and fatality risk as including two contributions. First, a contribution is made by what we refer to as the intrinsic effect of mass; included with the intrinsic effect of mass is the effect of size, because these are so strongly correlated.[3] Second, there is a design-related factor. Particular small cars may differ from particular large cars in ways not intrinsically related to their size; for example, if a small car with a rear engine crashed head-on into a large car with a front engine, the relative fatality risk might be larger than if both cars had similarly located engines. Contributions from such differences in some particular early models might generate a small effect on the overall relationships. Apart from this factor, we interpret the car mass effect for pre-1970 cars as reflecting an intrinsic mass effect for a fleet of cars of relatively homogeneous design features but differing in mass. Thus $u \cong 3.7$ represents the mass effect when two cars with similar design features crash into each other.

From the mid-1970s onward, some vehicles were subject to major redesign in which new methods and technologies were applied to manage crash energy dissipation in ways calculated to reduce the injury risk to occupants. Small cars tended to be the first to benefit from such redesign. It thus seems plausible that the lower values of $u$ for mid-1980s cars (for example, $u = 2.3$ for model year 1984) reflect design as well as intrinsic mass effects. Thus the greater risk associated with the smaller car was partially offset by the smaller car's having crashworthiness features not yet incorporated into larger cars. It is also possible that redesign resulted in stiffer structures, which might reduce risks to occupants traveling in the redesigned car but increase risks to occupants in struck cars. This could have a large effect on the fatality ratio, because the numerator would decline while the denominator increased.

As the 1980s proceeded, large cars were subject to the same redesign attention previously devoted to small cars. Thus, as the crashworthiness of the large

cars increased, the relative disparity in risk appeared to be moving back to reflect the same intrinsic mass effect that applied to the earlier model years. At present it is not possible to determine whether values of $u$ will continue to increase and will approach, reach, or exceed their previous levels. However, the trend is consistent with the interpretation that $u$ may approach a new stable value of ~3.7, which represents the intrinsic effect of mass when cars are otherwise of homogeneous design. The much lower $u$ values of the mid-1980s cars were a temporary aberration reflecting effects of both mass and design. Figure 2 shows definitively that the disparity in risk between small and large cars is not continuing to decline and is now clearly greater than the minimum reached for model year 1984.

The results presented here offer a clear interpretation of earlier unexplained findings[2–4] of large differences between older (model year 1979 and earlier) and newer (model year 1980 and later) cars. The $u$ values of 3.53 for older and 2.75 for newer cars[2] are in accord with the values shown in Figure 1 (taking into account weighting by the number of data). Conclusions based on an assumption that the results for model years 1980 and later would apply into the future underestimate the effect of mass on safety. The replacement of heavier cars by lighter cars is expected to result in an increase in fatalities substantially greater than was previously estimated.[4] Indeed, calculations based on the car mass–fatality relationship for older cars may estimate future effects more accurately than those based on the relationship for newer cars.

All results presented in this paper are presented in terms of relative risk; they suggest that in the future, occupant risk in a small car will exceed that in a large car by a factor similar to that observed in the past. However, risks to drivers in all cars are expected to decline in the future, as they have in the past.[1,7] Factors that uniformly reduce crash risk do not affect the relationships reported here, even though they reduce the absolute number of driver fatalities. For example, if the nation were to become teetotal, traffic fatalities in essentially all categories would be reduced by approximately half.[1] As a result, the effectiveness of all occupant protection devices (and other safety measures) in reducing the absolute number of fatalities would likewise be halved, but without affecting relative risk relationships such as those reported here. Universal use of safety belts or airbags might have a small effect on the relative risk ratios reported (in addition to the main effect of reducing casualties in all types of vehicles). Although belts offer similar proportionate risk reduction in cars of all sizes, as discussed earlier, a recent finding[8] suggests a somewhat higher effectiveness in larger cars. As airbags also appear to be more effective in large cars than in small cars,[9] universal use of belts and airbags will tend to further increase the already great relative disadvantage in the smaller car. The absolute risk, rather than the relative risk, is, of course, more relevant in discussions of the cost-effectiveness of such expensive occupant protection features as increased vehicle mass or airbags.

The present study has, of necessity, focused exclusively on two-car crashes. Although about 78% of car occupants who are killed are killed in crashes other than two-car crashes,[1] the general conclusions reported here are likely to apply also to other crash types for which direct examination is not technically possible (assuming the validity of the explanation in terms of vehicle redesign).

## Conclusions

When a car of a given model year crashes into another car of the same model year but 50% heavier, the driver in the lighter car is more likely than the other driver to be killed by a factor of about 3.7 to 5.1 for 1966 through 1979 model year cars, 2.6 for 1984 model year cars, and 4.1 for 1990 model year cars. These changes appear to be related to vehicle redesign. The smaller effect of car mass for the mid-1980s model years may be a result of smaller cars' containing crashworthiness improvements not yet introduced into larger cars.

In the future the relative safety disadvantage of smaller cars is expected to more closely resemble the larger effects found for pre-1979 model year cars; recent estimates based on data for all model year 1980 or later cars underestimate the extent to which driver fatality risk increases with decreasing car mass. Accordingly, future fatality increases resulting from increases in corporate average fuel economy standards will likely be greater than estimated on the basis of mid-1980 data. □

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