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Combining FARS And GES Data To Estimate Air Bag Effectiveness

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16. Abstract

To estimate fatality risks in crashes involving cars, FARS and GES files for the years 1991-1999 were combined. For the analyses, crashes were selected by type for a large part of the U.S.

Mathematical models expressing the driver fatality risks in cars without air bags as functions of driver age and sex, car weight, and speed limit were developed for single car crashes and collisions between cars.

These models were applied to crashes involving cars with air bags, and the difference between the modelled risk and the actual deaths used to estimate air bag effect.

It was found that air bags reduced the driver fatality risk by 33% in single-car, non-rollover crashes, and by 42% in collisions between two cars. Reductions were also found in side impacts.

These estimates depend critically on the assumption that presence of an air bag does not increase reporting of non-fatal crashes involving cars with them.

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Executive Summary

In this study, air bag effects were estimated by comparing driver fatality risks per crash involvement in cars with and without air bags. To calculate fatality risks, FARS and GES data were combined. This required excluding the Northeastern states and California because of missing vehicle identification numbers. Crash data from 1991 through 99 were used. Cars of the model years from 1985 on were studied. Single car, non-rollover crashes, and collisions between two cars were studied separately.

Mathematical models were developed expressing how the driver fatality risk in cars without air bags depended on vehicle weight, driver age and sex, and the speed limit as a very crude proxy of travel speed. Safety belt use could not be considered because the information is not sufficiently reliable. Therefore, the estimated air bag effect are in addition to those of safety belts.

These models were used to predict the risks drivers of cars with air bags would have found, if they had been in cars without air bags. Comparing these with the actual experience showed the effect of air bags.

It was found that in collisions with other cars, air bags reduced driver deaths by 42%, with an estimated error of 5%. In cars with frontal impacts, the reduction was 45% with an estimated error of 5%.

In single car, non-rollover crashes, air bags reduced driver fatalities by 33%, with an estimated error of 5%. In frontal impacts, the reduction was 44% with an estimated error of 6%.

Surprisingly, air bags also seemed to reduce driver deaths in side impacts in collisions: by 29% (7) for right side impacts, 19% (9) for left side impacts (error estimates in parentheses). There might also be smaller and less certain reductions in side impacts in single car crashes.

It was also studied whether air bag effectiveness depended on car weight, driver age, driver sex, or speed limit. The only apparent pattern was that the effect seemed to be greater for women than for men.

These findings have to be interpreted with caution because they depend critically on how complete the police reporting of non-fatal crashes is. In less severe crashes, air bags cause minor injuries. If that should increase the number of police reported non-fatal crashes from which GES samples, the ratio of killed drivers to involved drivers would decrease, even if the actual fatality risk did not decline.

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Abbreviations and Other Conventions

FARS: Fatal Analysis Reporting System (previously the Fatal Accident Reporting System)

GES: General Estimates System - a component of NASS

Graphs: Size of the circles is approximately proportional to the number of deaths represented by the data point, not the number of cases. Sizes are not comparable between different graphs.

The value of a number is the smaller of the number of FARS cases, and the actual GES cases from which the risk is calculated. The size of the character is approximately proportional to the number of deaths represented by the data points. Sizes are not comparable between graphs.

Some graphs contain legends and text in the body of the graph. If they are not self-explanatory, or conflict with the caption, they should be ignored.

NASS: National Automotive Sampling System (previously National Accident Sampling System)

Non-standard error:
Errors calculated by the STATA routine SVYLOGIT. This routine does not consider all levels of the GES sampling plan. Also, variables are included in the models on the basis of extensive preceding analyses. Therefore, the distribution of the non-standard errors is unknown.

PJ: Police Jurisdiction. The second level of clusters, within the PSUs, of the GES sampling plan. Also called secondary sampling units in the statistical literature.

PSU: Primary Sampling Unit. The first level clusters in the GES sampling plan.

PSU stratum:
12 strata of the GES sampling plan, defined by cross-classification of Region and Type - Central City, Suburban, other.

Region: Northeast, South, Central (or Midwest) and West.

Stratum: 4 strata of the GES sampling plan are defined by crash type.

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1. Introduction

1.1 Background and objectives

This work had two main objections: 1) to estimate the effectiveness of air bags with fewer assumptions than other approaches require, doing this by combining FARS and GES data, and 2) to examine how well FARS and GES data can be combined.

The common approaches to estimate air bag effectiveness use relative risks, the ratio of the risks in cars equipped with air bags to those in cars without air bags, without calculating the absolute risks separately. For instance, one can calculate the relative risks in collisions between cars with and without air bags. This gives relative risks in collisions, but not for other crash types. Another comparison is between driver and right front seat occupants, using cars with no air bags, cars with only a driver air bag, and cars with air bags for both front seat occupants. This can be applied to all crashes, but crashes with two front seat occupants are likely to differ in some respect from crashes where there is only the driver and no other front seat occupant present (for instance, car occupancy is higher on rural roads than in urban areas). A third approach is based on the fact that air bags are designed to deploy in frontal impacts, and assumes that they have no effect in side impacts. In fact, however, air bags do deploy in many side impacts and therefore can have at least some effect (even in side impacts, cars will typically experience a deceleration, and deploying air bags can protect the occupant against striking the interior of the vehicle in front of him).

Absolute fatality risks can be calculated from the number of driver deaths (or for occupants of specific seating positions) in crashes divided by the number of drivers (or other specified occupants) in crashes. In principle, state accident data files contain most of the necessary information. However, the number of fatal crashes in any single state's file is small, and the fatality risk estimates are not very precise. The only data base with sufficient number of fatal crashes is FARS. However, there is no corresponding nationwide file of non-fatal crashes. The closest to that is GES, which is a sample of about 50,000 mostly non-fatal, but also including some fatal crashes, each of which represents between 2 (not 2,000) and 3,000 actual crashes. This allows, in principle, to calculate fatality risks with greater statistical precision than can be obtained from state files, which are also nationally representative, less dependent on factors or conditions peculiar to individual states. There are, however, a number of technical difficulties that make a combined analysis of the FARS and GES files less than straightforward.

1.2 The data

The data bases were prepared by the Volpe National Transportation System Center from the original FARS and GES data files, adding information obtained by decoding the VIN. Crash data for the years 1991-99 were used. Two types of files were created: 1) for single vehicle crashes, where the first event was not a rollover (also excluding a few rare crash types), 2) for collisions between two cars.

To determine the presence of an air bag in a car, the Vehicle Identifications Number is needed. It is also needed to determine the weight of the car, which is an important confounding factor. The FARS files contain the VIN for nearly all cars. In GES files, many VINs are missing. Some are randomly missing, but there is a strong systematic pattern by geographical region as defined in the GES. With two exceptions, within a PSU either nearly all, or nearly no VINs are given for cars. The following pattern appears:

Northeast:	1 PSU with all VINs, 2 with some, 11 with none
Central (also called Midwest):	12 with, 4 without VINs
South:	17 with, 1 without VINs
West:	7 with, 5 without VINs

Since for most GES cases in the Northeast VINs were not available, all GES cases from this region were omitted from the study. Correspondingly, all FARS cases from the states composing the Northeast were also omitted. This posed no problem of matching because the regions were defined by the states they were composed of.

In the Central and Southern regions, in most PSUs, the cars in GES cases had VINs. In these regions, all cases from the PSUs without VINs were omitted, and the expansion factors for the cases from the PSUs with VINs adjusted. This results in statistically valid estimates of police reported crashes in these regions, and allows to combine them with the fatal crashes from FARS in these regions.

The West posed an additional problem. Nearly half of the PSUs had no VINs, all in California. From a purely formal point of view, the same procedure as for the Central and Southern regions could be applied: the data from the 7 PSUs with VINs could be used with adjusted expansion factors, to estimate police reported crashes. However, these 7 PSUs are all outside of California which not only accounts for the vast majority of crashes in the Western region, but also differs in many respects from the other states. Therefore, the results would most likely be biased.

To avoid such a bias, the approach was modified. A new region, the West excluding California (WxCA) was defined. The data from the 7 useable PSUs were used to make estimates of police reported crashes for WxCA (in this case the adjustments of the expansion factors were more complicated). Correspondingly, the FARS cases from California were omitted. Again, this resulted in a statistically valid match of FARS and GES cases in the WxCA region.

For the analyses, the FARS and GES cases for single vehicle crashes were combined, and separately those for collisions. GES cases with a fatality were omitted, and FARS cases were assigned a expansion factor of 1. Adding a 0/1 variable indicating driver survival (GES cases) or death (FARS cases) as dependent variable, one can use statistical techniques to estimate fatality risks.

1.3 Modeling

Air bags are only one of many factors which influence the fatality risk in a crash. Some other factors have a much stronger effect. A very obvious factor is crash configuration. The risk differs between single vehicle crashes and collisions, it depends on the impact direction and its point on the vehicle, and on the impacting part of the other vehicle in a collision. Such factors are best accounted for by studying different collision configurations separately. The effects of other factors can be captured by mathematical modeling. The following are very rough illustrations of the order of magnitude of the effects some factors have over their range from the lowest to the highest values found in crashes:

speed limit	1:50 (low to high)
age of the driver of the case car	1:15 (young to old)
age of the driver of the other car in a collision	1.5:1 (young to old)
sex of the driver of the case car	1.5:1 (man to woman)
sex of the driver of the other car in a collision	1.5:1 (man to woman)
weight of the case car	2:1 (2,000 to 4,000 lb)
weight of the other car in a collision	1:5 (2,000 to 4,000 lb)

Other important factors are the effect of alcohol (in this context not on the occurrence of a crash, or its severity in terms of delta-V or a similar measure, but in terms of the probability of dying from the injuries suffered in the crash), and the use and type of safety belts. These two factors could not be considered, because even in FARS information on alcohol is far from complete, and in GES even more so. Information on safety belt use in FARS appear to be fairly reliable if a driver is dead at the scene, but much less so if he dies later. In GES, it must be considered unreliable.

Initially, we considered all factors listed above. Speed limit is only an imperfect proxy for actual travel or impact speed. Actual travel speed may be much higher, and sometimes much lower (the difference may be correlated with driver age and sex). In a collision at an intersection, the speed limit is usually that of the higher order road, typically higher than that on the cross road. Nonetheless, its empirical effect is so strong that one should include it.

The second strongest effect is that of driver age. The fatality risk increases in a highly non-linear manner with age: up to about 40 years roughly linear, faster between 40 and 60, and rapidly increasing with higher ages. This is probably a combination of two effects: young drivers driving faster (relative to the speed limit) and thereby increasing their risk, older drivers driving closer to the speed limit, but being more vulnerable. This is suggested by the effect of the age of the "other" driver in a collision: the fatality risk declines with his or her increasing age. Women have a lower fatality risk, and also create a lower fatality risk for other drivers in a collision.

The effects of vehicle weight shown above are "pure" weight effects obtained from models. Driver age and vehicle weight are correlated: older drivers tend to drive heavier cars. Therefore, without adjusting for this, heavier cars would appear less protective than they actually are. On the other hand, heavier cars appear less aggressive in a collision than they actually are, compared with lighter cars.

Driver sex has similar effects. Women tend to drive lighter cars than men. This makes heavier cars appear less protective than they are, but also less aggressive in a collision.

More detailed analyses show that the effects of the factors are not always independent, but can interact.

In collisions, the characteristics of both drivers and vehicles play a role. Initially, both were used in the models. This, however, complicated the model development very much, and often some coefficients in the final model depended on only a few cases. Since there are only weak, if any correlations between the characteristics of the two vehicles and drivers in a collision, we decided to omit the "other" vehicles' and drivers' characteristics. This should not bias the results much, though it might increase their random errors.

There are basically two types of models: categorical and continuous. Categorical models collapse continuous data into relatively few "cells", calculate risks for each cell, and relate the risks to the driver, vehicle and speed values characterizing each cell. Their advantage is that one can identify interactions relatively easily. One great disadvantage is that defining the cells so that not too much information is lost (e.g. not creating cells where the fatality risk can not be calculated or cells within which the fatality risk varies widely) tends to be laborious. There are also other disadvantages.

Continuous models express the fatality risk as a mathematical function of the variables characterizing vehicles, drivers and speed. This requires assuming a mathematical form for this function, or experimenting to find one which fits the data well. This can also be laborious. However, we found that the same basic structure could be used for all models developed. For simple practical reasons, we used a logistic model: the statistical package STATA offered very efficient routines for it.

We did not use it for the specific mathematical form of the logistic function which is not always most suitable for modeling fatality risks. In our case, however, the logistic model was practically equivalent to a multiplicative model of the form

$$risk=a * \exp(b * x) * \exp(c * y) * \exp(d * z)...$$

where the x,y,z,... can be the variables themselves or interactions of variables. To represent highly non-linear (or in this case, in effect, non-exponential) relations, we used “kinky” relations, e.g. by adding a new variable which was equal to the age if it was over 40, and 0 otherwise, etc. For vehicle weight, we found that a logarithmic transformation, x=log(weight) nearly always gave the best model fit. This amounted, in effect, to having a weight term of the form weight^b for the risk.

The fit of the model was assessed, not only by overall comparisons of actual with predicted risks, but also by comparing them with respect to each of the variables used, and with respect to several of their interactions.

1.4 How to estimate air bag effectiveness.

To estimate air bag effectiveness, one has three basically different approaches.
1) One models the fatality risk in cars without air bags. The model is applied to cases involving cars with air bags, and the differences between the actual deaths, and the modelled risks are studied. 2) One develops separate models for the risk in cars with air bags, and for cars without air bags. The difference between the two modelled risks describes air bag effects. 3) One develops one model for all cars, with and without air bags, which includes terms for the presence of the air bag, and its interaction with selected variables.

Cars with air bags appeared with the 1985 model years (the number of earlier cars with air bags is negligible). Cars without air bags can be of much older vintage and therefore may not satisfy the FMVSS applicable to more recent cars. To avoid confounding air bag effects with those of the FMVSS and other long term changes in car design, only cars of model years 1985 or later were used for modelling.

We experimented briefly with approaches (2) and (3), but because the models were fairly complicated, found the results to be “fragile”, depending strongly on which terms were included in the model, because the models were fairly complicated. Therefore, we used approach (1).

2. Estimating air bag effectiveness

There is no single best measure of air bag effectiveness. One may be characterized as "descriptive": it quantifies the reduction of deaths for a large aggregate of crashes, e.g. all crashes involving cars in the entire US during one year, usually as a percentage, sometimes as an actual number. Another type of measure may be - less accurately - be characterized as "functional": expressing the fatality risk reduction in very specific crash configurations as a function of certain crash factor.

Descriptive measures aggregate functional measures for many different crash types, including rare types for which only imprecise estimates can be made. While descriptive estimates are important for evaluating the overall effect (and the cost-effectiveness) of air bags, functional estimates provide a better insight into how air bags work, and possibly suggest directions for improvement.

This study produced functional and descriptive estimates. It treated collisions between two cars, and crashes involving a single car, excluding those with a rollover as first event, separately. For each of these two categories, the effect in all crashes was estimated, and also separately the effects in cars with frontal impacts, with right side impacts, and with left side impacts.

In all cases, models were developed which controlled for the following confounding factors: speed limit, weight of the cars for which the fatality risk was estimated, driver age, and driver sex. Interactions of these factors were also explored and included in the models where they improved the model fit.

It was also attempted, with not much success, to determine how air bag effectiveness depended on these factors.

2.1 Car-car collisions

The analysis in 2.1.1 uses all collision configurations, including impacts involving corners, front to rear impacts, and even other rear impacts. It gives the most comprehensive estimates of air bag effectiveness in car-car collisions.

The analysis of cars with frontal impacts (2.1.2) uses only case vehicles with 12 o'clock impacts in FARS, or impact 1 in GES. It combines cases from front-front collisions, front-side collisions, and collisions including corners or the rear end. It covers cases in which the air bag is designed to deploy, if a certain crash severity is exceeded. One would expect the greatest air bag effects in these cases.

Sections 2.1.3 and 4 deal with front/right-side, and front/left-side impacts, respectively. "Right-side" is defined by 3 o'clock for FARS, and by impact code 2 for GES cases, "left side" by 9 and 3, respectively. Air bags are not designed to deploy in such crashes, though they often do. One would expect low, if any, air bag effects in such crashes.

Data from one collision may be used in several subsets. If one of the cars is of model year >1984, the other of model year < 1985, then only the more recent car will be used in 2.1.1, and if it has a FARS impact code of 12, 3, or 9, or a GES impact code 1,2, or 3 in one of the sections 2.1.2, 2.1.3, or 2.1.4

If both are of model year > 1984, then both cars will be used in 2.1.1; one or both of them may also be used in 2.1.2, 2.1.3, or 2.1.4, depending on the impact on the car: 12, 3, or 9 for FARS cases, 1,2, or 3 GES cases.

A subtle statistical difficulty arises in the case of front-front collisions when both cars are included as case vehicles in the modelling. Then, the two "observations" they represent in the statistical analysis are not strictly independent. This means that the error estimates for the model coefficients are too low because they ignore the lack of independence. We had planned to avoid this by "bootstrapping" the errors of the model coefficients, but this turned out to be too complicated.

In the case of single car crashes, the analyses in 2.2.1, 2.2.2, 2.2.3, and 2.2.4 correspond to those in 2.1.1, 2.1.2, 2.1.3, and 2.1.4. However, since there is only one car per case, the problem of lack of independence and its effect on the estimated errors of the coefficients does not arise.

2.1.1 All collision configurations

Air bags are designed to deploy in frontal impacts. Therefore, the intended effect is best measured in crashes with frontal impacts. However, air bags also deploy in other than frontal impacts and may then have an effect. Also, to assess the overall societal effect of air bags, it is useful to know how much they reduce deaths in "all" or at least broad classes of crashes. Therefore, we also estimate the effects of air bags in all configurations of collisions between two cars.

To do this, we developed models for the driver fatality risk in "all collisions between two cars. Such models must be interpreted with caution: since injury mechanisms differ among impact configurations, any mathematical model for "all" collisions combines implicitly the functions for different impact configurations. Even if the functions for different impact configurations had similar patterns, the combined function may have a very different pattern. Thus, it may not reflect causal relations, and should not be interpreted as such.

Table 2.1.1-1 shows the numbers of study cars which could be used for modeling. These numbers are greater than the numbers of collisions, because in some collisions each car could be used as a study car. A very crude estimate of air bag effectiveness is obtained from the cross-product ratio of the case numbers, 0.82, which would indicate a 18% reduction of the fatality risk. However, this ignores the varying expansion factors of the GES cases - from little over 2 to about 3,000 - , and confounding factors which might be correlated with the presence or absence of an air bag. The fatality reduction after modelling the confounding factors is 42% (Table 2.1.1-3).

Table 2.1.1-1 Numbers of usable study cars for all configurations of collisions between two cars.

cars with	FARS	GES
no air bag	10498	45135
air bags	13603	71243

Table 2.1.1-2 shows the coefficients of the best model which could be fitted to the data. The "non-standard errors" are those obtained by the STATA procedure SVYLOGIT. They might be good approximations for the standard errors in the usual sense. However, we use the term "non-standard" because of some conceptual questions, discussed in Appendix B.

When comparing the coefficients with the non-standard errors, that for the speed limit of 65 mph would not be considered significant by the conventional criteria. However, it clearly improved the fit of the data, but because the number of cases affected is small, it has a large error. Also, a positive coefficient for this speed limit it is consistent across several subsets of the data.

The coefficient for the calendar year is surprising: it represents a drop of the fatality risk by about 3% each year. This is not an indirect effect of a trend with model year or with car age, because the calendar year could not be replaced by car age, or model year. One may speculate that this is an effect of increasing safety belt use over time. However, a closer examination shows that one could replace this linear trend by a step function between 1992 and 1993.

The constant term is an indicator of the fatality risk for a 30 year old man in a 2,800 lb car, in 1990, on a road with a speed limit of 50 mph:

$$\text{risk} = \exp(-6.39)/(1+\exp(-6.39)) = 1.68/1000$$

Figure 2.1.1-1 shows the actual risk versus the risk calculated by the fitted model. The overall agreement is very good. This, however, does not mean that the model fits the data in every detail. There can be gross discrepancies between the model in relation to certain factors, or interactions of factors. Therefore, further comparisons were made. Figures 2.1.1-2 through 21 show actual and modelled risks versus each of the variables used in the model, also disaggregated by another variable.

Table 2.1.1-2 Model coefficients for the driver fatality risk in cars without air bags in collisions between two cars.

variable	coefficient	non-standard error
(splimit - 50)/10	.76	.08
splimit =55	1.0	.23
splimit =65	.32	.21
log (weight/2800) ∗ (splimit<55)	-1.97	.14
log (weight/2800) ∗ (splimit=55)	-1.53	.15
(age -60) ∗ (splimit -55)/100	.055	.013
(age -50) ∗ (age >50) ∗ (splimit >60)/100	.38	.13
(age -50) ∗ (age >50) ∗ (weight >2800)/10	-.11	.03
female	-.40	.05
(age -30)/10	.15	.02
(age -60) ∗ (age >60) ∗ male/10	.62	.09
(age -40) ∗ (age >40) ∗ female/10	.32	.04
year - 1990	-.03	.02
constant	-6.39	.22

Figure 2.1.1-2 shows actual and modelled risks versus car weight. The agreement between actual and modelled risks is very good. The risks show a step decline from the lowest weight to those above 2,300 lb, from there on a linear decline to 2,900 lb, and above that no change with car weight. This should not be interpreted to mean that weight above 2,900 lb offers no protection. Higher weights are correlated with higher driver age which in turn is correlated with the fatality risk. The combined effect of these two factors may keep the risk approximately constant. To assess the effect of car weight alone, corrected for this confounding, one should look at the coefficients in Table 2.1.1-2.

Figures 2.1.1-3 through 8 show actual and modelled risks versus car weight, disaggregated by speed limit, driver age, and driver sex. In all cases, the agreement between the actual and the modelled risks is very good, except for the point with the highest car weight for female drivers.

Figures 2.1.1-9 through 14 show driver fatality risks versus driver age, disaggregated by driver sex, car weight, and speed limit. In all cases the agreement between the actual and modelled risks is very good. However, there is a small systematic deviation for the points at ages 70 and 80, which is similar for women, cars of 2,800 lb or lower weight, and speed limits of 55 mph or higher.

Figures 2.1.1-15 through 21 show actual and modelled risks versus speed limit, overall, and disaggregated by the other factors. Because the risks cover a wide range, a logarithmic scale was used for them. Overall, the points are close to a straight line which indicates that the driver fatality risk increases approximately exponentially with the speed limit. The major exception is the speed limit of 55 mph, for which the risk is always higher. There are some other, but much smaller deviations. By including categorical terms for certain speed limits, the model accommodates these deviations.

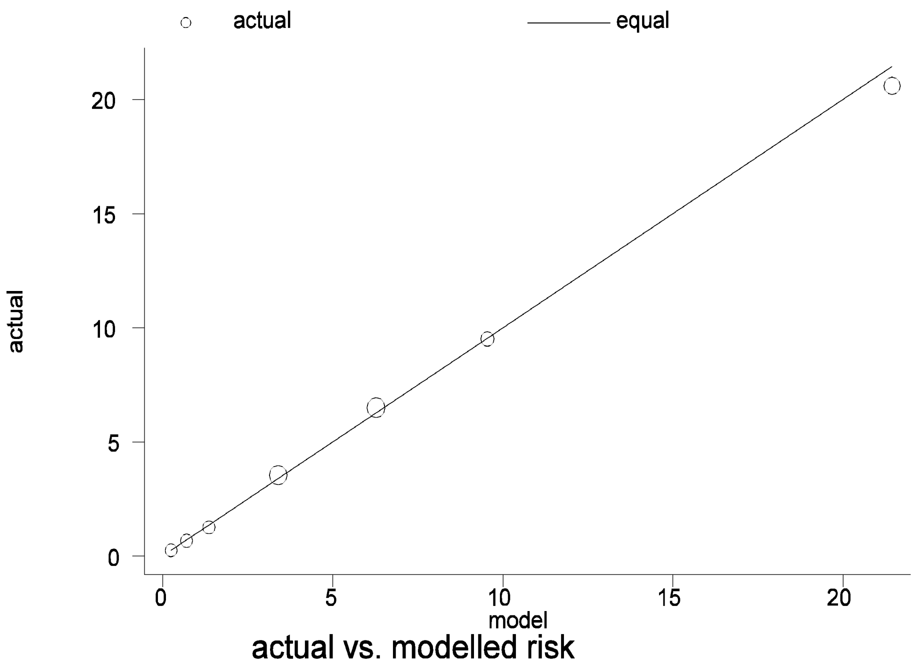


Figure 2.1.1-1 Actual versus modelled driver fatality risk (per 1,000 involvements) in car-car collisions . Study car without air bags.

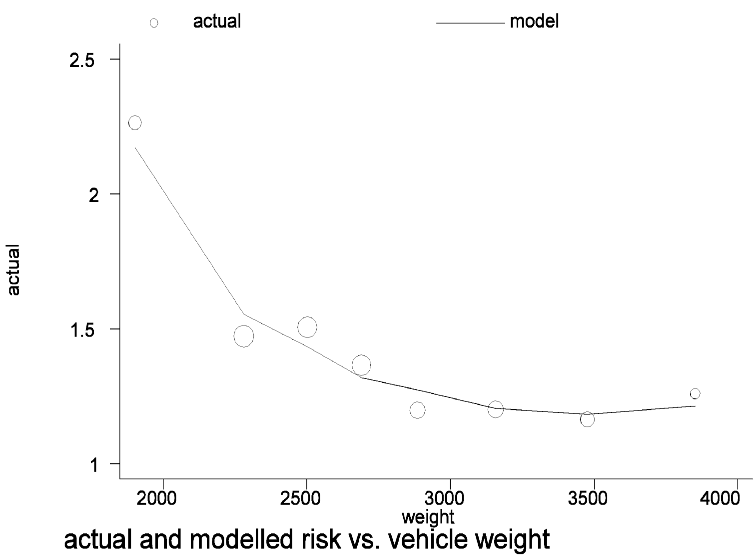


Figure 2.1.1-2 Actual and modelled driver fatality risk (per 1,000 involvements) in car-car collisions versus weight of study car. Study cars with no air bag.

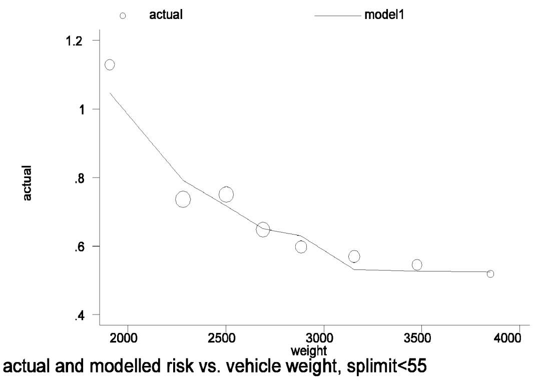


Figure 2.1.1-3 Actual and modelled driver fatality risk (per 1,000 involvements) in car-car collisions versus weight of study car. Speed limit <55 mph. Study cars with no air bag.

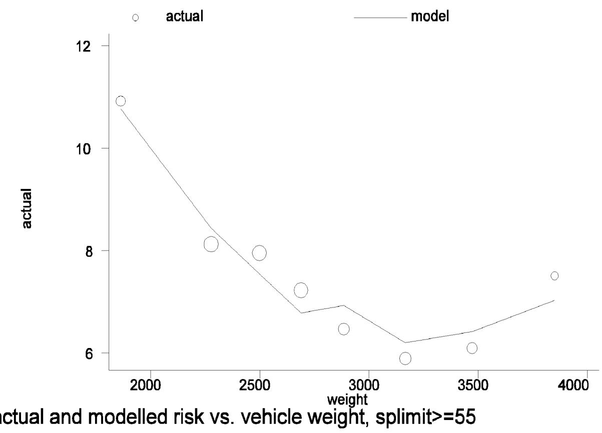
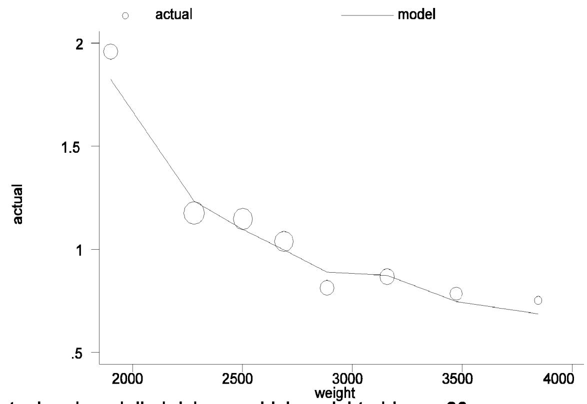
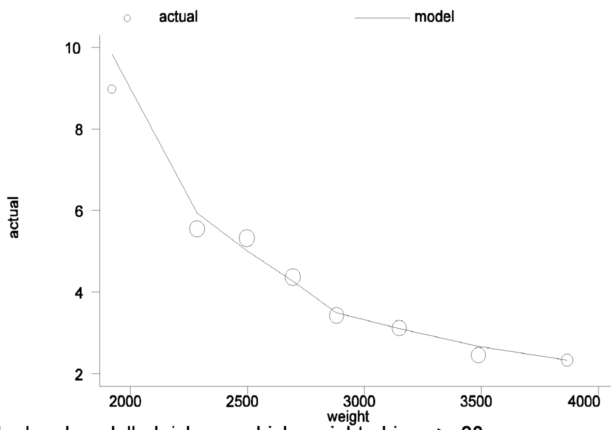


Figure 2.1.1-4 Actual and modelled driver fatality risk (per 1,000 involvements) in car-car collisions versus weight of study car. Speed limit >= 55 mph. Study cars with no air bag.



actual and modelled risk vs. vehicle weight, drivers<60

Figure 2.1.1-5 Actual and modelled driver fatality risk (per 1,000 involvements) in car-car collisions versus weight of study car. Driver <60 years old. Study cars with no air bag.



actual and modelled risk vs. vehicle weight, drivers>=60

Figure 2.1.1-6 Actual and modelled driver fatality risk (per 1,000 involvements) in car-car collisions versus weight of study car. Driver 60 or more years old. Study cars with no air bag.

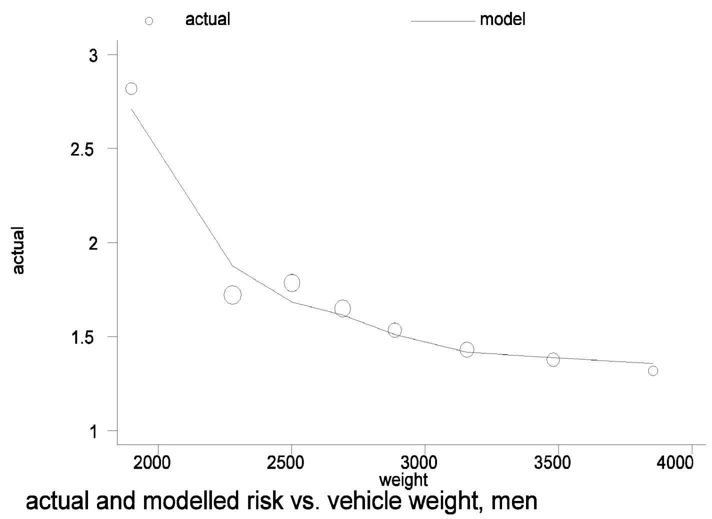


Figure 2.1.1-7 Actual and modelled driver fatality risk (per 1,000 involvements) versus weight of study car. Male driver. Study cars with no air bag.

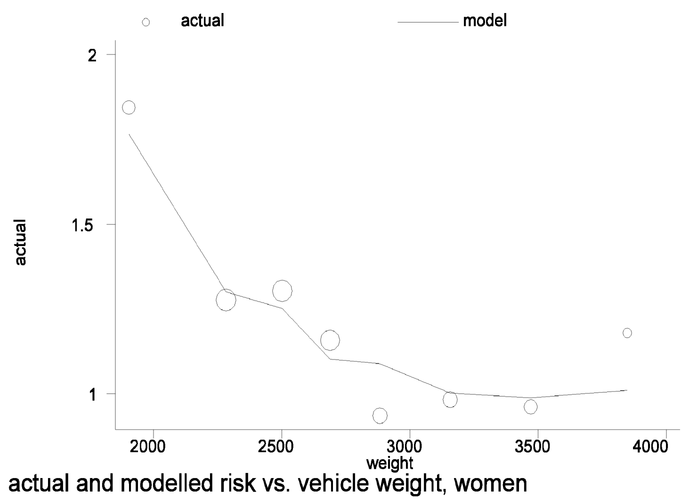


Figure 2.1.1-8 Actual and modelled driver fatality risk (per 1,000 involvements) versus weight of study car. Female drivers. Study cars with no air bags.

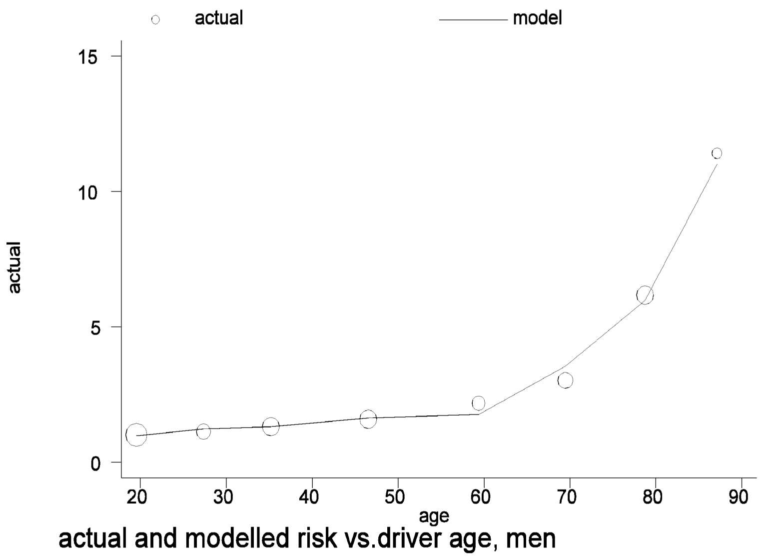


Figure 2.1.1-9 Actual and modelled driver fatality risk (per 1,000 involvements) versus driver age. Male drivers. Study car without air bags.

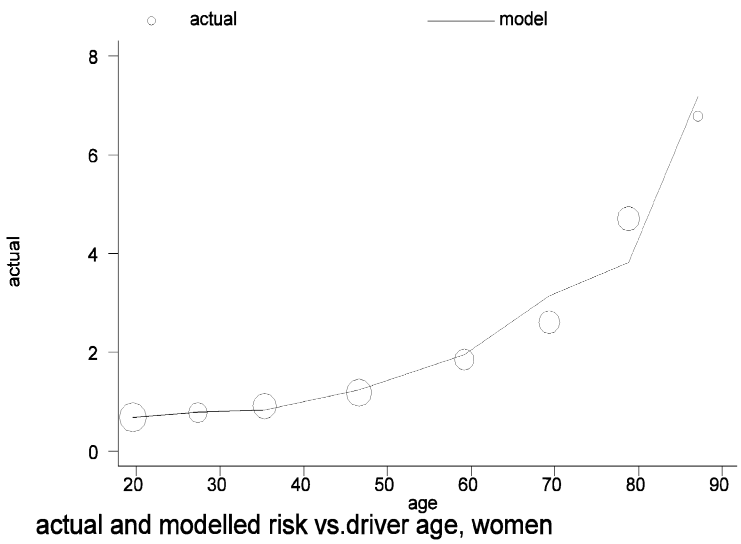


Figure 2.1.1-10 Actual and modelled driver fatality risk (per 1,000 involvements) versus driver age. Female driver. Study car with no air bags.

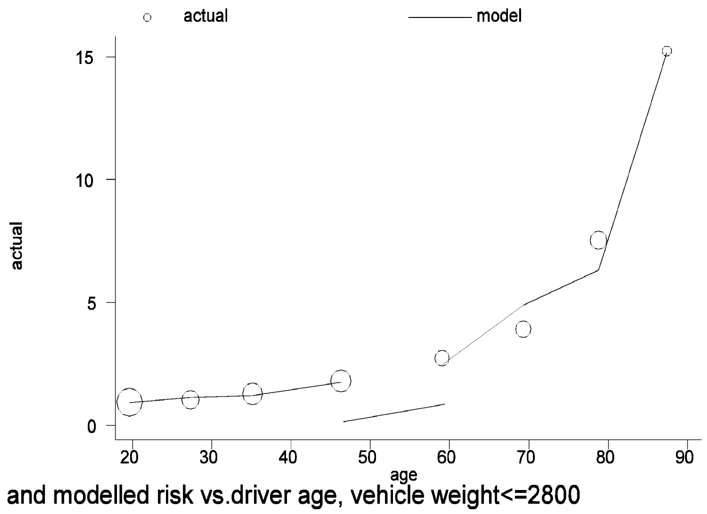


Figure 2.1.1-11 Actual and modelled driver fatality risk (per 1,000 involvements) versus driver age. Car weight <= 2,800 lb. Study cars with no air bags.

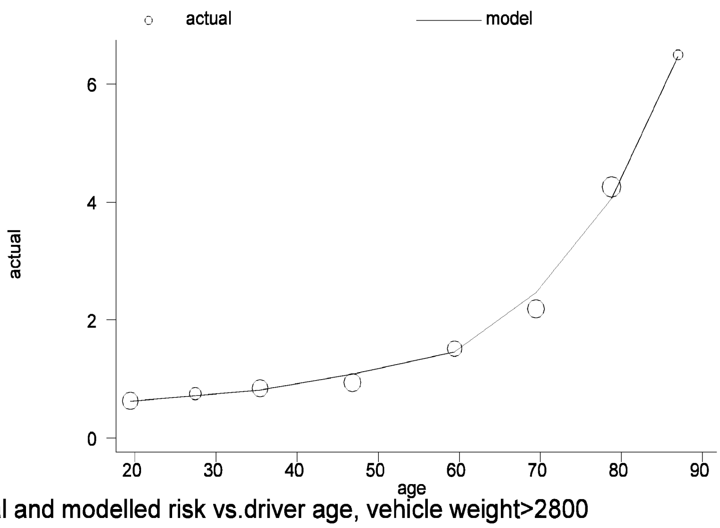


Figure 2.1.1-12 Actual and modelled driver fatality risk (per 1,000 involvements) versus driver age. Car weight > 2,800 lb. Study cars with no air bags.

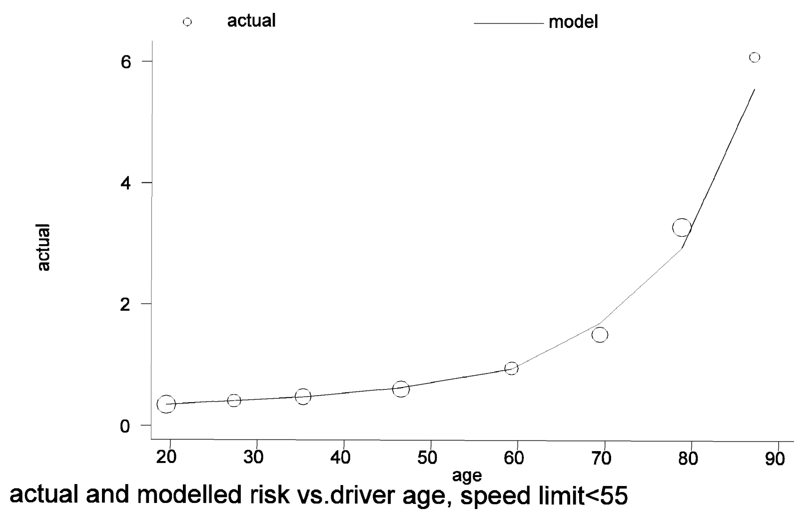


Figure 2.1.1-13 Actual and modelled driver fatality risk (per 1,000 involvements) versus driver age. Speed limit <55 mph. Study cars with no air bags.

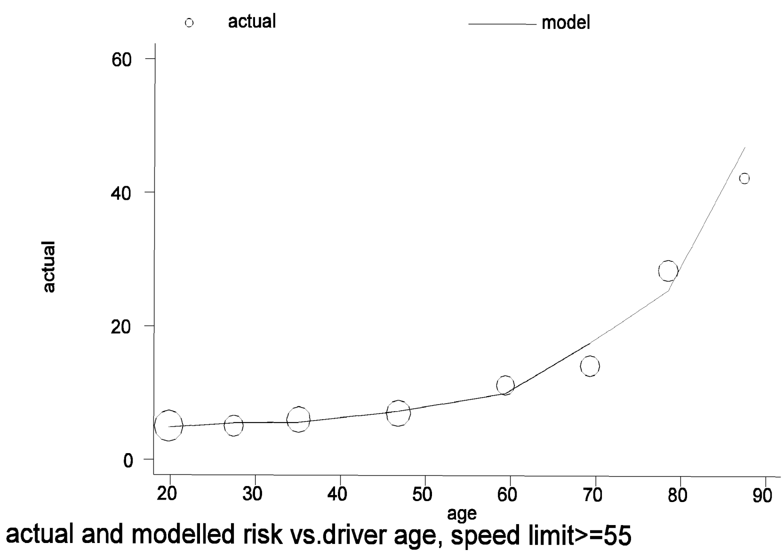


Figure 2.1.1-14 Actual and modelled driver fatality risk (per 1,000 involvements) versus driver age. Speed limit >=55 mph. Study cars with no air bags.

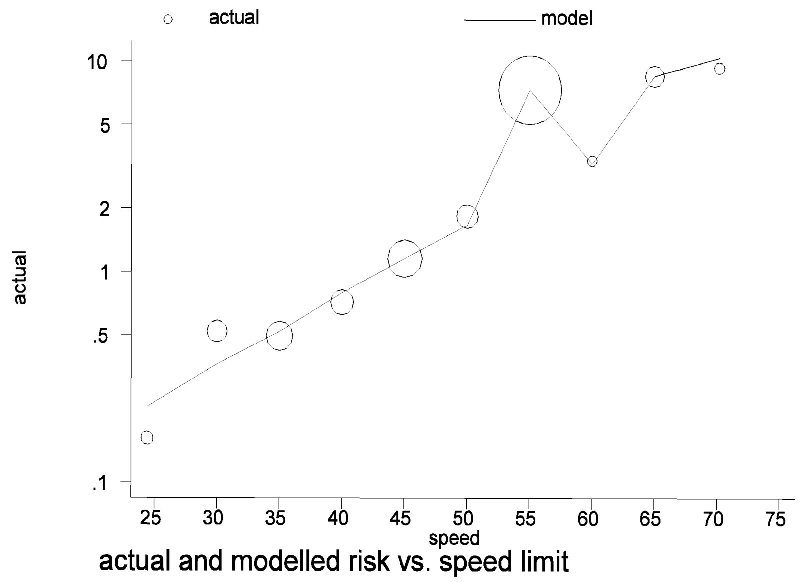


Figure 2.1.1-15 Actual and modelled driver fatality risk (per 1,000 involvements) versus speed limit. Study cars with no air bags. Logarithmic scale for risk.

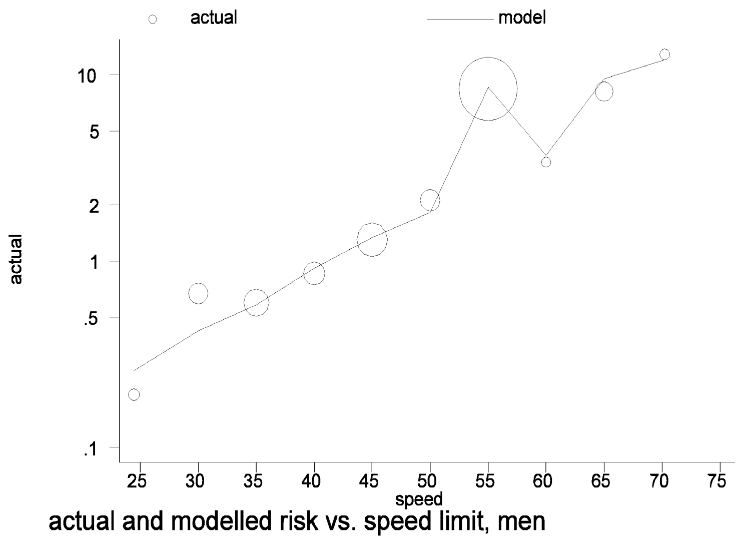


Figure 2.1.1-16 Actual and modelled driver fatality risk (per 1,000 involvements) versus speed limit. Male drivers. Study cars with no air bags. Logarithmic scale for risk.

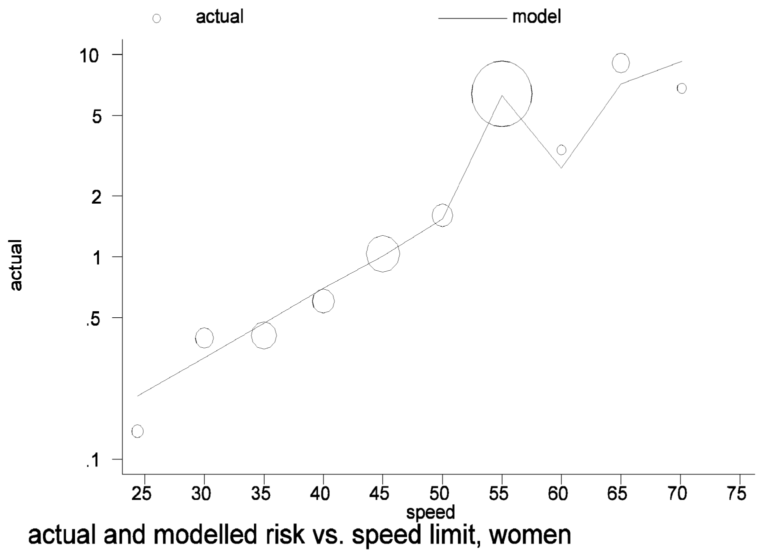


Figure 2.1.1-17 Actual and modelled driver fatality risk (per 1,000 involvements) versus speed limit. Female drivers. Study cars with no air bags. Logarithmic scale for risk.

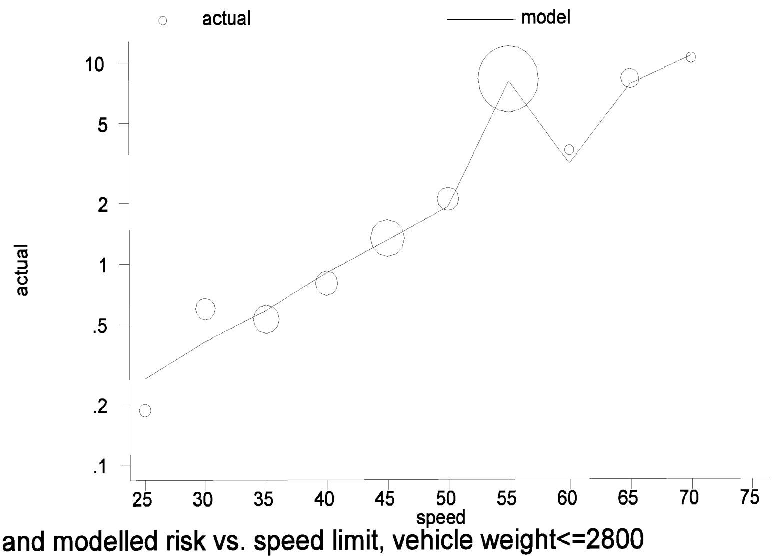


Figure 21.1-18 Actual and modelled driver fatality risk (per 1,000 involvements) versus speed limit. Cars <= 2,800 lb. Study cars with no air bags. Logarithmic scale for risks.

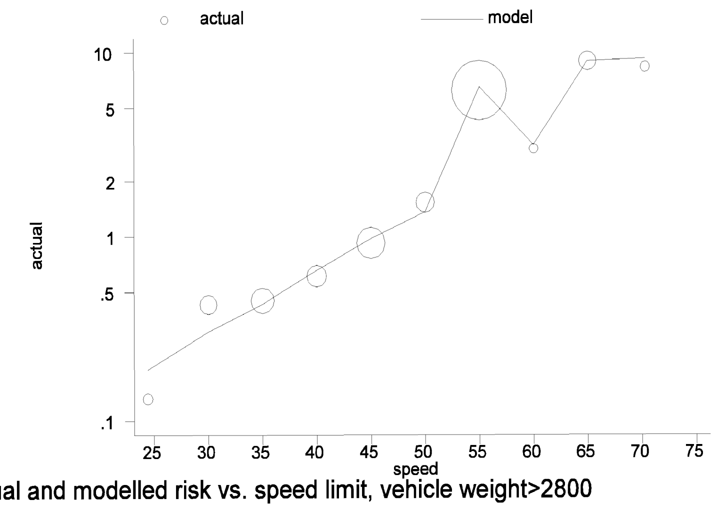
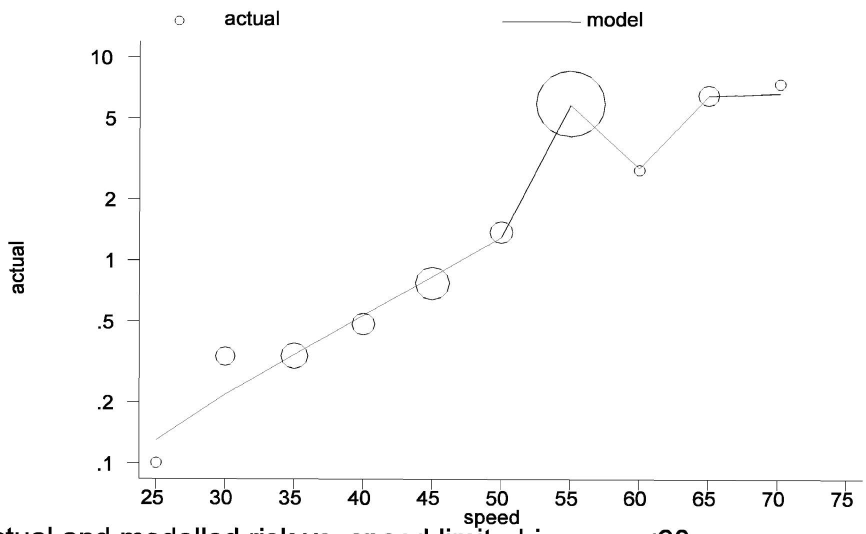
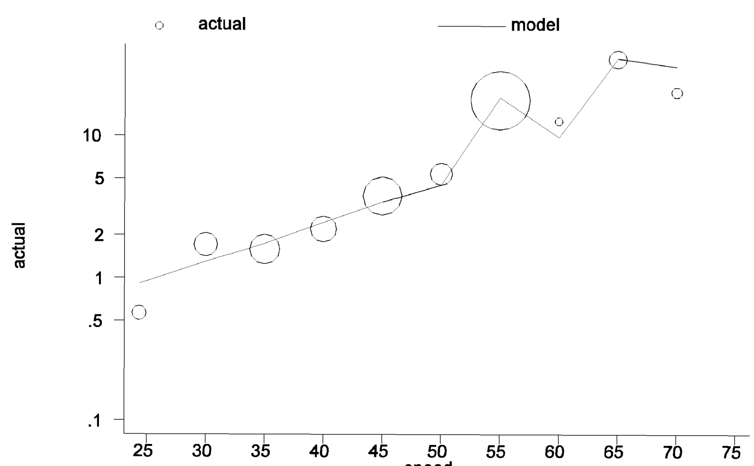


Figure 2.1.1-19 Actual and modelled driver fatality risk (per 1,000 involvements) versus speed limit. Cars >2,800 lb. Study cars with no air bags. Logarithmic scale for risks.



actual and modelled risk vs. speed limit, driver age<60

Figure 2.1.1-20 Actual and modelled driver fatality risk (per 1,000 involvements) versus speed limit. Driver age <60. Study cars with no air bags. Logarithmic scale for risks.



actual and modelled risk vs. speed limit, driver age>=60

Figure 2.1.1-21 Actual and modelled driver fatality risk (per 1,000 involvements) versus speed limit. Driver age >= 60. Study cars with no air bags. Logarithmic scale for risk.

To estimate the effects of air bags, this model was used to predict for cars with air bags in the combined FARS and GES files the fatality risk their drivers would have faced, had their cars not had air bags, using their air bag cars' values for driver age, driver sex, car weight and speed limit. The actual driver deaths were summed (the expansion factors for these cases equaling 1), and the predicted risks summed, weighted by the expansion factors. This gave an estimate of the driver deaths which would have occurred if the cars had not had air bags. Their ratio gave the factor by which driver deaths had been reduced by air bags.

For each car with an air bag

(actual - predicted)/predicted,

where "actual" is 0 if the driver survived, 1 if he died, and "predicted" is the risk predicted by the model for cars without air bags, gives an estimate of risk reduction by the air bags by averaging them over all air bag cases with the expansion factors or weights. If the air bag effect is constant across all cases, both estimates give the same effect. However, if air bag effectiveness is correlated with the fatality risk, the estimates will differ. If the air bag effectiveness is higher in cases with higher predicted risk, then the overall fatality reduction will be greater than the average of the case-by-case effects. On the other hand, if the air bag effect is greater in the cases with lower predicted risks, then overall effect will be smaller than average of the case-by-case effects.

Table 2.1.1-3 shows the results. Estimates by the two methods practically agree, well within their non-standard errors. It is surprising that these estimates are much greater than the 18% calculated in a very crude manner from the car counts in Table 2.1.1-1.

Table 2.1.1-3 Air bag effects in collisions between two cars (percent reduction of driver deaths). Non-standard errors in parentheses.

estimate	cars with air bags	cars with driver only air bag
reduction of total deaths	42 (5)	34 (6)
average of reduction of fatality risks	41 (6)	35 (7)

Estimates for cars with driver only air bag could be made with minimal additional effort, and were made to take a different look at the robustness of these estimates. Surprisingly, they are lower, though still by not or only little more than their non-standard errors (note that these two estimates are not independent). This means that the effectiveness of the driver air bag must be much greater in cars with dual air bags than in those with driver only air bags.

Figure 2.1.1-22 shows the actual driver fatality risks in cars with air bags versus those predicted for drivers of the same age and sex, in cars with no air bags, of the same weight, and for the same speed limit. Figure 2.1.1-23 shows the same, but with double logarithmic scales. In the first figure, the points fall close to a straight line with a slope different from 1, in the second, they fall around a straight line with a slope of 1, but offset against the line representing equality. This shows that the fatality risk reduction is about constant for collisions of all severities, in terms of predicted fatality risk for non-air bag cars. The only exception is the point for very low predicted risks which has much higher actual risks.

Figure 2.1.1-24 shows the actual driver fatality risks in cars with air bags, and those expected for cars with air bags versus car weight. The actual values are always, and in all but one case substantially lower than the expected ones. Figure 2.1.1-25 shows the ratio of the two. For the lightest car, the risk is only 10% lower, for most 40%, and for the heaviest in the high 40 percents. Figures 2.1.1-26 and 27 show the same data, disaggregated by speed limit. For lower speed limits, the points show only wide scatter, but for high speed limits, a clearly decreasing trend with weight - indicating increasing air bag effectiveness - appears.

Figures 2.1.1-28 and 29 show the same relation disaggregated by driver age. Here, for younger driver effectiveness is clearly increasing with car weight, for older drivers no such trend is apparent.

Figures 2.1.1-30 and 31 show the relation disaggregated by driver sex. For men, there is, with the exception of the point for the lightest cars, no clear trend apparent, whereas for women a strong, fairly consistent increase of air bag effectiveness appears: from 10% for the lightest to nearly 55% for the heaviest cars.

With regard to driver age, Figures 2.1.1-32 and 33, no simple pattern is recognizable for men, but for women there seems to be an increase in effectiveness up to an age of 45 years, followed by a leveling off, and a dramatic decline for the highest ages.

With regard to speed limit, Figure 2.1.1-34, a large effect of 55% appears for 40 mph, while it is around 40% for the other speed limits, without any pattern. This holds also if one disaggregates by other factors.

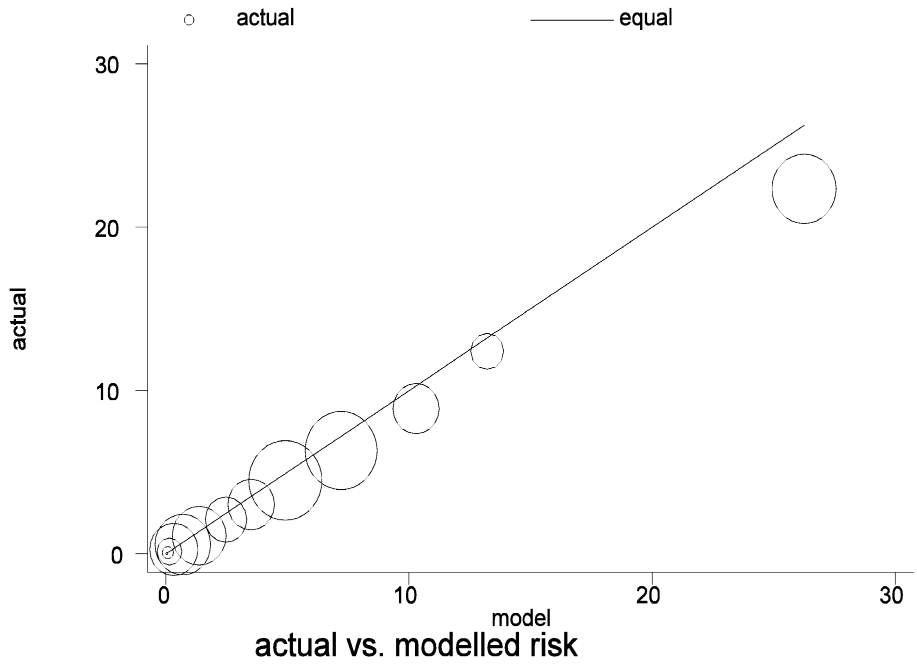


Figure 2.1.1-22 Actual driver fatality risk (per 1,000 involvements) in cars with air bags versus risks predicted from model for cars without air bags. Car-car collisions. The line represents equality of actual and predicted risks.

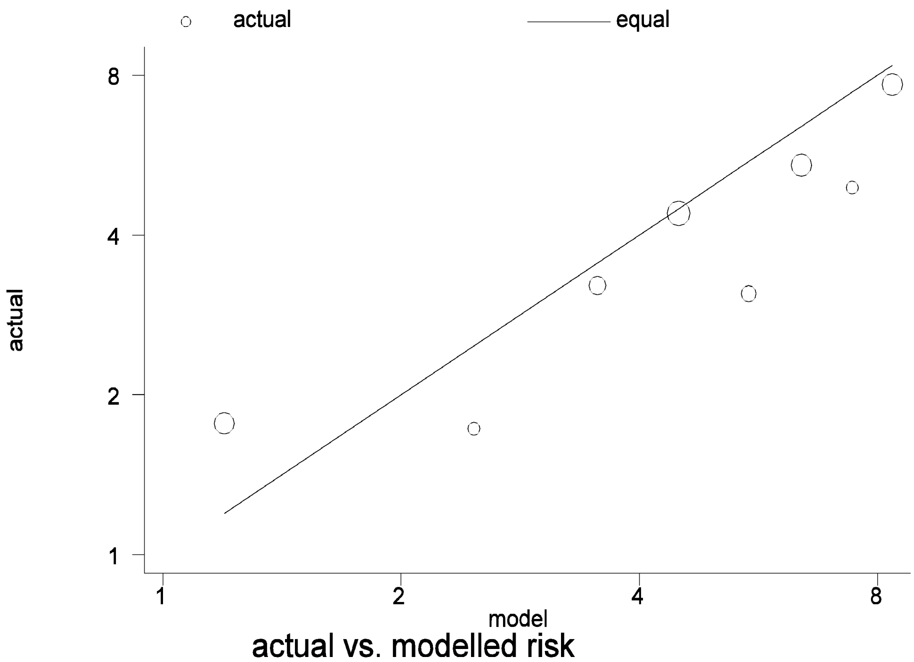


Figure 2.1.1-23 Actual driver fatality risk (per 1,000 involvements) in cars with air bags versus risks predicted from model for cars without air bags. Car-car collisions. Double logarithmic scales. The line represents equality of actual and predicted risks.

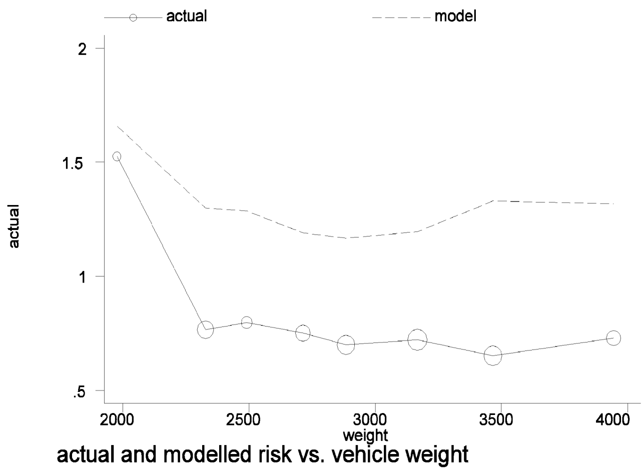


Figure 2.1.1-24 Actual driver fatality risk in cars with air bags, and the corresponding risk predicted from the model for non-air bag cars versus car weight. Collisions between two cars.

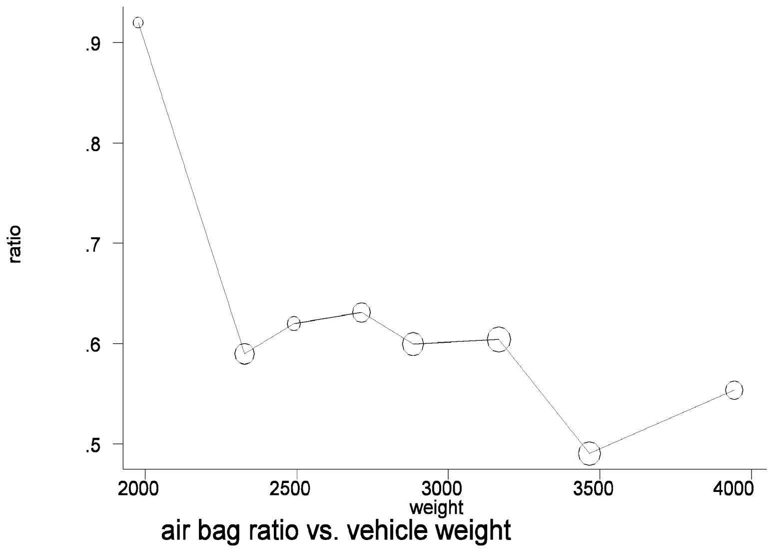


Figure 2.1.1-25 Ratio of the actual driver fatality risk in cars with air bags to that expected for cars without air bags versus car weight. Collisions between two cars.

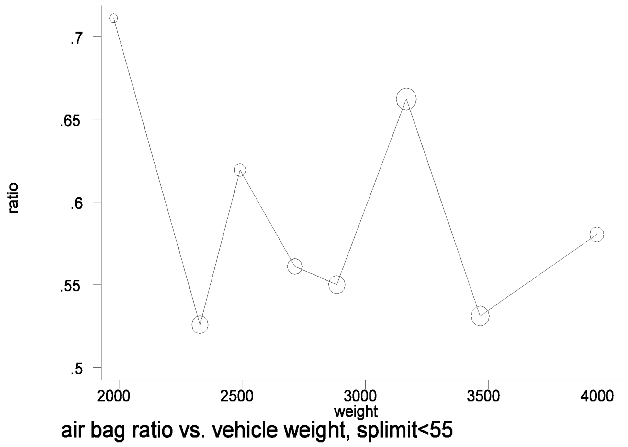


Figure 2.1.1-26 Ratio of the actual driver fatality risk in cars with air bags to that expected for cars without air bags versus car weight, speed limit <55 mph. Collisions between two cars.

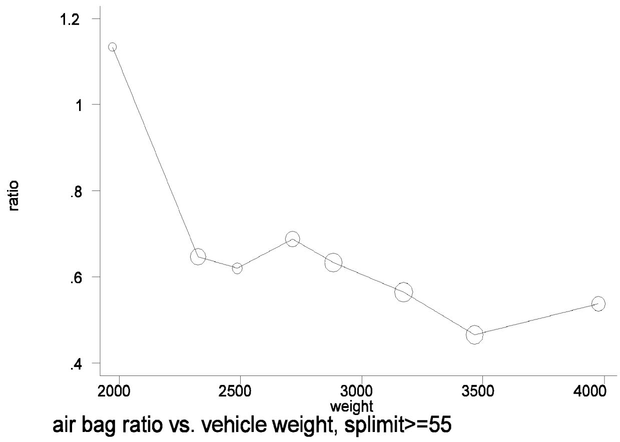


Figure 2.1.1-27 Ratio of the actual driver fatality risk in cars with air bags to that expected for cars without air bags versus car weight, speed limit > =55 mph. Collisions between two cars.

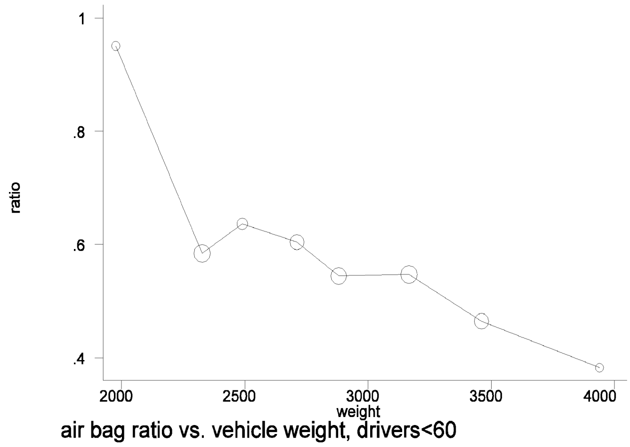


Figure 2.1.1-28 Ratio of the actual driver fatality risk in cars with air bags to that expected for cars without air bags versus car weight. Driver age < 60 years. Collisions between two cars.

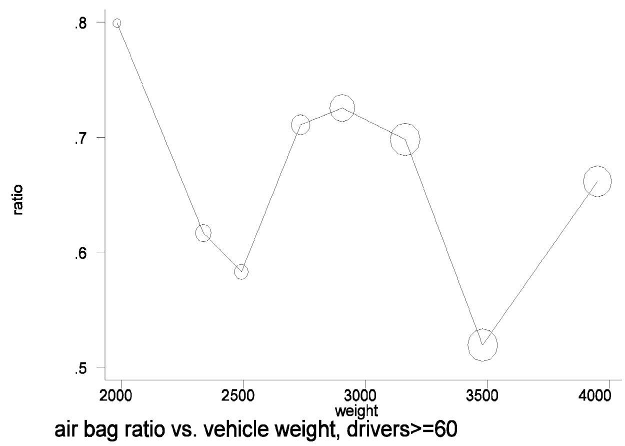


Figure 2.1.1-29 Ratio of the actual driver fatality risk in cars with air bags to that expected for cars without air bags versus car weight. Driver age > =60 years. Collisions between two cars.

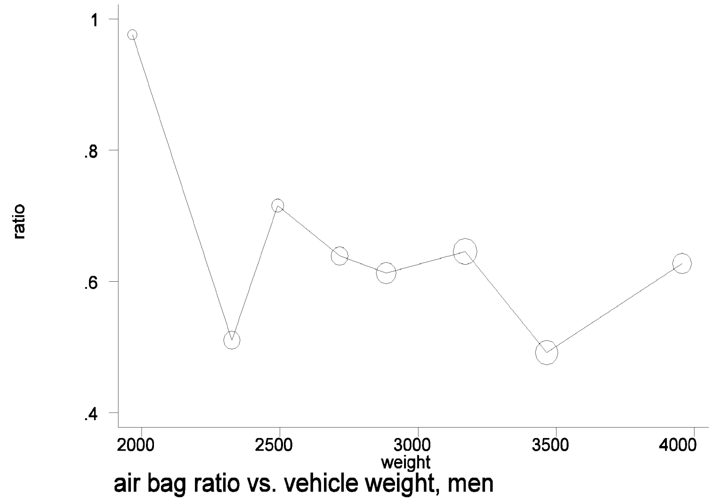


Figure 2.1.1-30 Ratio of the actual driver fatality risk in cars with air bags to that expected for cars without air bags versus car weight. Male driver. Collisions between two cars.

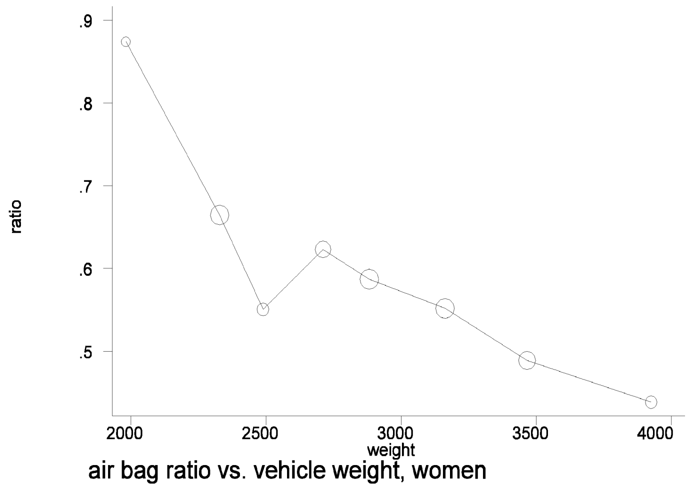


Figure 2.1.1-31 Ratio of the actual driver fatality risk in cars with air bags to that expected for cars without air bags versus car weight. Female driver. Collisions between two cars.

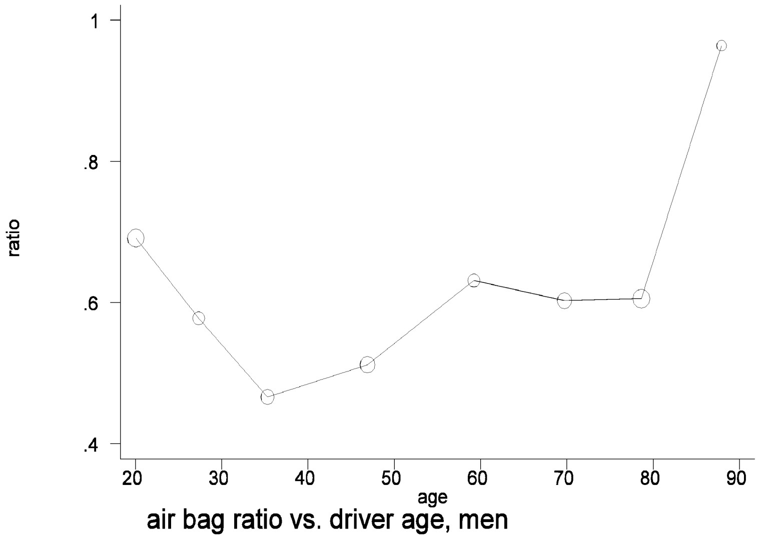


Figure 2.1.1-32 Ratio of the actual driver fatality risk in cars with air bags to that expected for cars without air bags versus driver age. Male driver. Collisions between two cars.

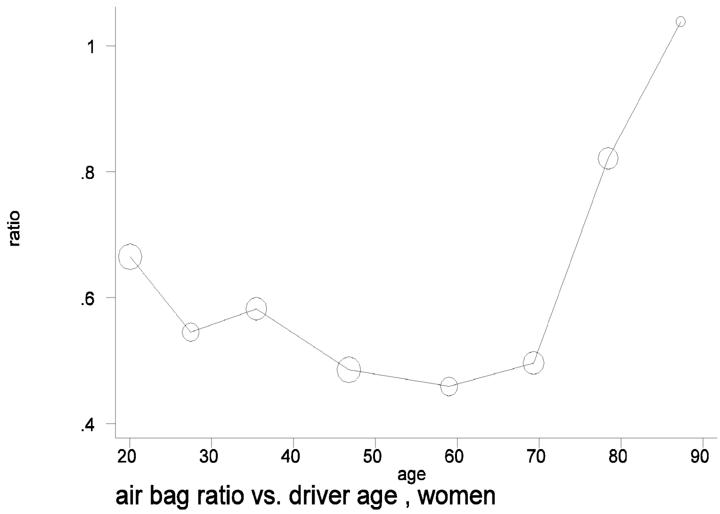


Figure 2.1.1-33 Ratio of the actual driver fatality risk in cars with air bags to that expected for cars without air bags versus driver age. Female driver. Collisions between two cars.

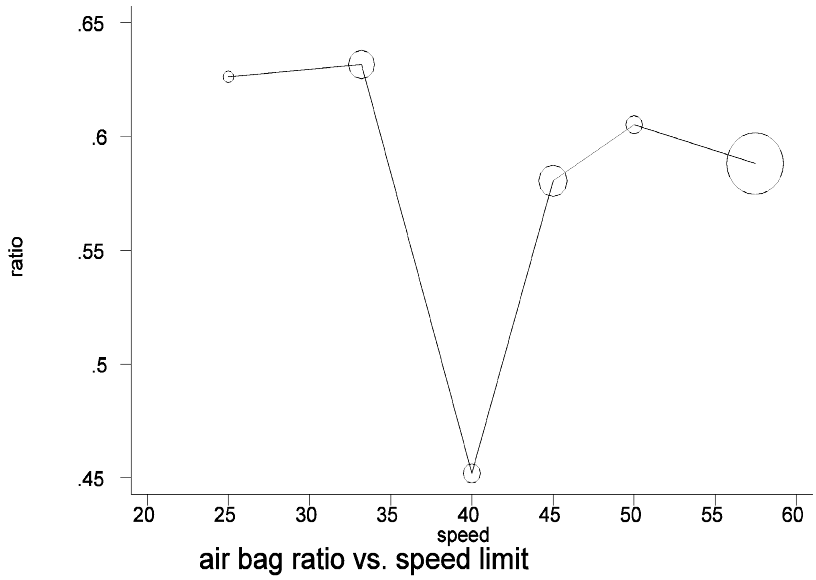


Figure 2.1.1-34 Ratio of the actual driver fatality risk in cars with air bags to that expected for cars without air bags versus speed limit. Collisions between two cars.

Some of these figures suggest that air bag effectiveness depends on interactions of several factors. To explore this further, exploratory regressions were run. The ratio death/predicted-risk for each case was used as dependent variable, and weight, age, sex and speed limit and their products as independent variables. Forward and backward regressions were used. Since the result of such regressions are often "fragile", sometimes variables were excluded, sometimes forced in, and sometimes only groups of variables allowed to be entered or excluded.

The result was that a term "female" appeared in all models, either directly or in interactions with car weight. Other factors were at best marginally "significant". Table 2.1.1-4 shows the coefficients of the best models. None of them is clearly better at representing the data.

Table 2.1.1-4 Coefficients of models for air bag effectiveness in collisions between two cars. A negative sign indicates a beneficial effect. Non - standard errors are in parentheses.

variable	coefficients			
	model 1	model 2	model 3	model 4
female	-.18 (.07)		-.16 (.07)	
female ∗ log(weight/2,800)		-.57 (.17)	-.45 (.15)	-.54 (.16)
male ∗ log(weight/2,800)				.44 (.21)
constant	-.31 (.08)	-.40 (.06)	-.31 (.08)	-.41 (06)

Including both "female", and its interaction with car weight changes the coefficients of the separate models only little, well within their estimated errors. Model 4 uses only interactions between car weight and sex. The term for women differs relatively little from those in the other models. The term for men, however, is surprising, because it indicates a decrease of effectiveness with increasing car weight.

We also took a simple look at the data to assess how air bag effectiveness varies with on the factors: we split the data set by male/female and low/high values of each factor, and calculated the effectiveness for each of these subsets. The results are shown in Table 2.1.1-5. Since it required minimal additional effort, we calculated not only the effect for all cars with air bags, but also separately for cars with only driver air bags which are on the average of earlier vintage. One notices that in all but two cases where they are equal, air bag effectiveness is lower in cars with driver air bag only, which requires that it is higher in cars with dual air bags.

Table 2.1.1-5 Air bag effects in collisions between two cars (percent reduction of driver deaths), by different levels of pre-crash factors. E1 are estimates 1 - (actual driver deaths)/(expected driver deaths), E2 are averages of (1-deaths/risk) calculated for each case. Non-standard errors in parentheses.

subset of cases	cars with air bags		cars with driver only air bag	
	E1	E2	E1	E2
men	40 (6)	31 (7)	31 (7)	24 (8)
women	43 (6)	49 (6)	38 (6)	44 (7)
age <40 years	41 (7)	37 (7)	34 (7)	30 (7)
age >=40 years	43 (5)	47 (6)	34 (6)	42 (6)
car weight <= 2,800 lb	37 (6)	41 (7)	37 (6)	41 (8)
car weight > 2,800 lb	44 (5)	41 (6)	33 (6)	33 (7)
splimit <55 mph	42 (7)	41 (7)	37 (8)	36 (7)
splimit >= 55 mph	41 (7)	41 (7)	32 (8)	33 (8)

Estimates E2 are based on the ratio death/risk, and are therefore compatible with the regression results shown in Table 2.1.1-4. Model 1 predicts exactly the 31 and 49% reductions for men and women, respectively, shown in Table 2.1.1-5. The differences between men and women is much lower in the estimate E1. This indicates that women are more often in collisions with lower fatality risks, so that the higher effectiveness air bags have for them is translated into a lower total saving of lives, compared with that for men. A similar phenomenon appears with age: the difference between the effectiveness for young and old drivers is much greater if measured by E2 than measured by E1. This means that young drivers get into less severe - in terms of their own fatality risk - collisions than older drivers.

It is surprising that the estimates E2 suggest a strong effect of driver age, but that driver age did not appear as a “significant” factor in the exploratory regression.

2.1.2 Frontal impacts in car-car collisions

Air bags are designed to deploy in frontal impacts exceeding a certain severity. Therefore, the effects of air bags should be strongest in frontal impacts. Frontal impacts on the study car were identified by a FARS impact code “12", or a GES impact code “1". Any impact code on the “other” car was allowed. With this definition, the number of cases was still larger than the number of collisions, because most front-front collisions were used twice: once with one, once with the other car as study vehicle, if the selection criteria allowed this.

Table 2.1.2-1 shows the number of cases which could be used for modelling. A very crude estimate of air bag effectiveness is obtained from the cross-product ratio of the case numbers, 0.45 which would indicate a 55% reduction of the fatality risk. This simplistic estimate, however, ignores the varying weights of the GES cases, and confounding factors which might be correlated with the presence or absence of an air bag. The estimate controlling for these factors in 46% (Table 2.1.2-3).

Table 2.1.2-1 Numbers of cars with frontal impact on the study car, in car-car collisions. Note that the number of cars is greater than the number of collisions, some of which have two eligible cars with frontal impacts.

cars with	FARS	GES
no air bag	4,664	20,900
air bags	1,121	11,239

Table 2.1.2-2 shows the coefficients of the best model which could be fitted to the data. Comparison with those in Table 2.1.1-2 shows some similarities, e.g. with regard to speed limit and car weight, but also some greater differences with regard to driver age, mainly because of differences in the interactions necessary to fit the data.

Figure 2.1.2-1 shows the actual driver fatality risks versus those predicted by the model. The overall agreement is excellent; only the point representing the highest risk shows a slightly too high prediction.

Figures 2.1.2-2 through 20 show the actual and predicted risks versus the factors used in the model. In most graphs there are no systematic differences, though sometimes considerable scatter of the points.

With regard to weight (Figures 2.1.2-3 through 8), in a few cases the actual risk for the heaviest cars is higher than predicted, in some cases also the risk for the lightest cars. This, however, does not mean that modifying the car weight terms could result in a better fit; other factors correlated with the very high and very low weights could be causing these discrepancies.

Table 2.1.2-2 Model coefficients for the driver fatality risk in cars without air bags. Frontal impacts in car-car collisions.

variable	coefficient	non-standard error
(splimit - 50)/10	.95	.07
splimit =55	1.26	.23
splimit =65	.64	.25
log(weight/2,800) ∗ (splimit <55)	-2.12	.34
log(weight/2,800) ∗ (splimit > =55)	-1.15	.18
(age -70) ∗ (age >70) ∗ (splimit >60)/10	-.33	.20
(age-60) ∗ (age >60) ∗ (weight >2,800)/10	-.25	.09
female	-.28	.06
(age -30)/10	.33	.02
(age -70) ∗ (age >70)/10	.47	.10
year - 1990	-.03	.02
constant	-6.54	.20

With regard to driver age (Figure 2.1.2-9 through 14), the agreement is even better, with little scatter and no systematic deviations.

With regard to speed limit (Figure 2.1.2-15 through 20) the agreement at speed limits of 55, and at higher speed limits is enforced by two terms in the model. However, even for the six points representing lower speed limits, the agreement is very good, indicating that the fatality risk increases exponentially with the speed limit, because the coefficient 0.95 (Table 2.1.2-2) is roughly 1: exp (speed limit/10). This corresponds to an increase in the risk by a factor of 7.4 from highways with a 30 mph speed limit to those with 50 mph.

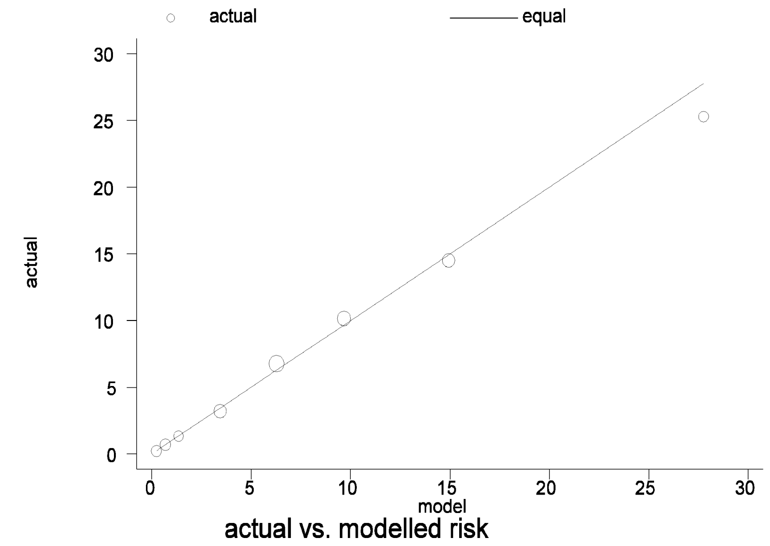


Figure 2.1.2-1 Actual versus modelled driver fatality risk (per 1,000 involvements) in cases with frontal impacts in car-car collisions. Study car without air bags.

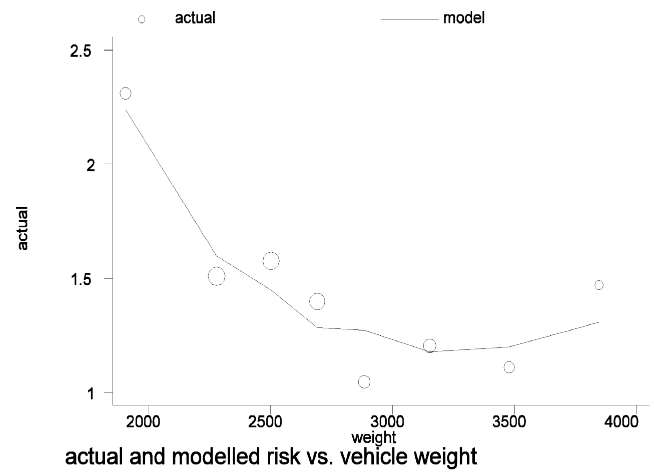


Figure 2.1.2-2 Actual and modelled driver fatality risk (per 1,000 involvements) in cars with frontal impact in car-car collisions versus weight of study car. Study cars with no air bags.

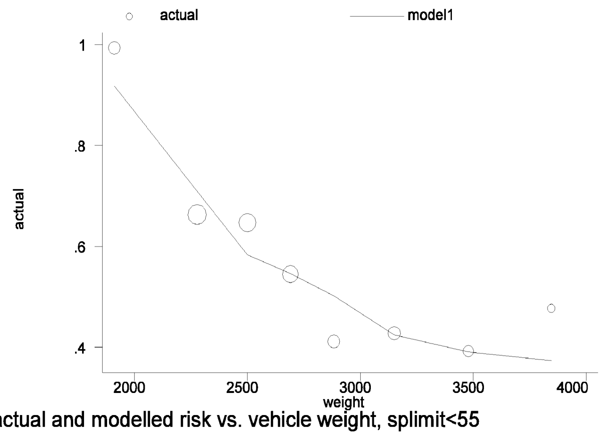


Figure 2.1.2-3 Actual and modelled driver fatality risk (per 1,000 involvements) in cars with frontal impact in car-car collisions versus weight of study car. Speed limit <55 mph. Study cars with no air bags.

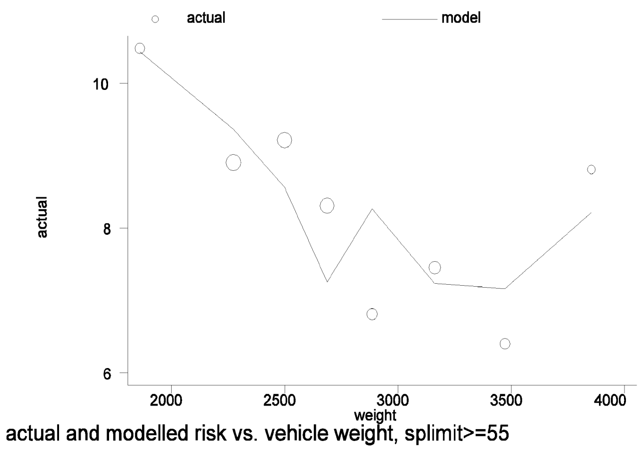


Figure 2.1.2-4 Actual and modelled driver fatality risk (per 1,000 involvements) in cars with frontal impact in car-car collisions versus weight of study car. Speed limit > = 55 mph. Study cars with no air bags.

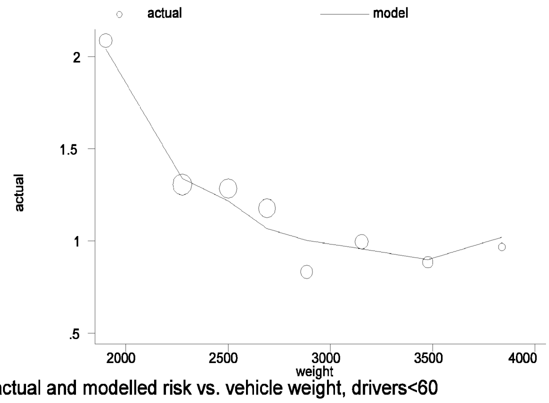


Figure 2.1.2-5 Actual and modelled driver fatality risk (per 1,000 involvements) in cars with frontal impact in car-car collisions versus weight of study car. Driver <60 years old. Study cars with no air bags.

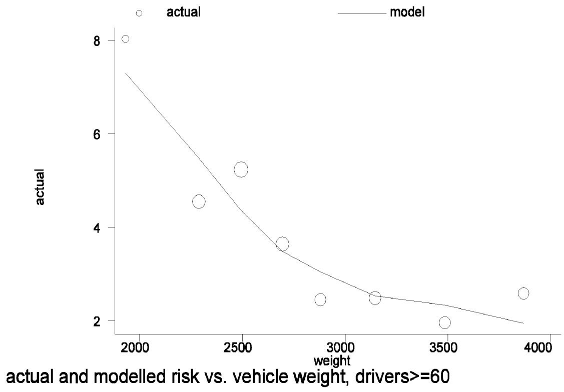


Figure 2.1.2-6 Actual and modelled driver fatality risk (per 1,000 involvements) in cars with frontal impact in car-car collisions versus weight of study car. Drivers 60 or more years old. Study cars with no air bags.

Figure 2.1.2-7 Actual and modelled driver fatality risk (per 1,000 involvements) in cars with frontal impact in car-car collisions versus weight of study car. Male driver. Study cars with no air bags.

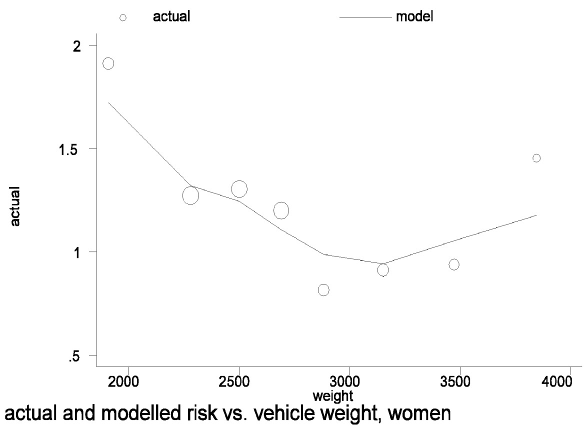


Figure 2.1.2-8 Actual and modelled driver fatality risk (per 1,000 involvements) in cars with frontal impact in car-car collisions versus weight of study car. Female driver. Study cars with no air bags.

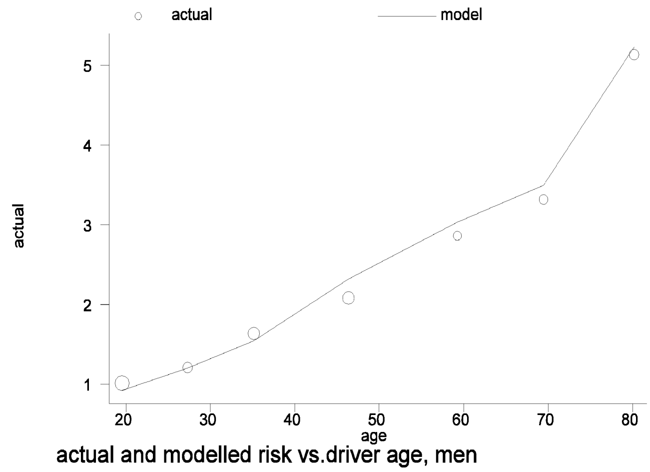


Figure 2.1.2-9 Actual and modelled driver fatality risk (per 1,000 involvements) in cars with frontal impact in car-car collisions versus driver age. Male driver. Study cars with no air bags.

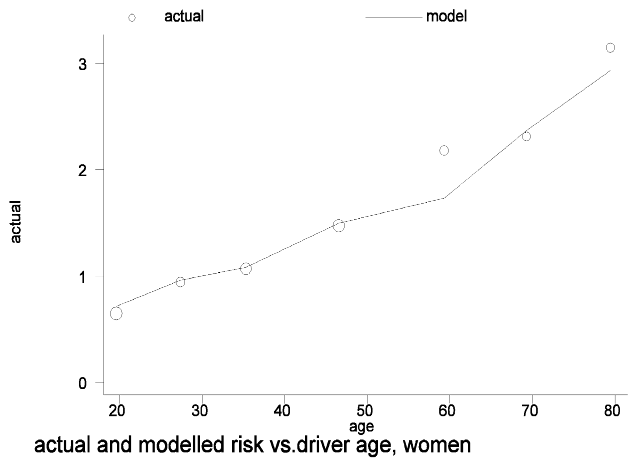


Figure 2.1.2-10 Actual and modelled driver fatality risk (per 1,000 involvements) in cars with frontal impact in car-car collisions versus driver age. Female driver. Study cars with no air bags.

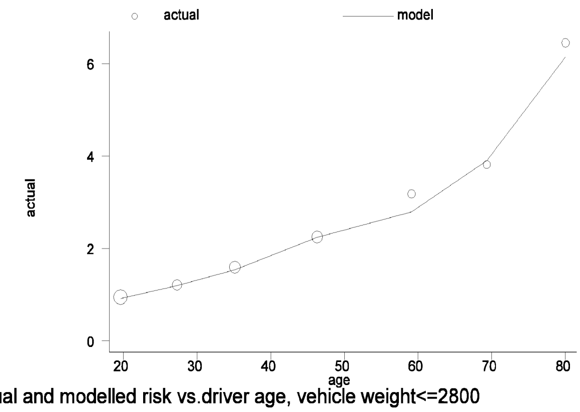


Figure 2.1.2-11 Actual and modelled driver fatality risk (per 1,000 involvements) in cars with frontal impact in car-car collisions versus driver age. Car weight < =2,800 lb. Study cars with no air bags.

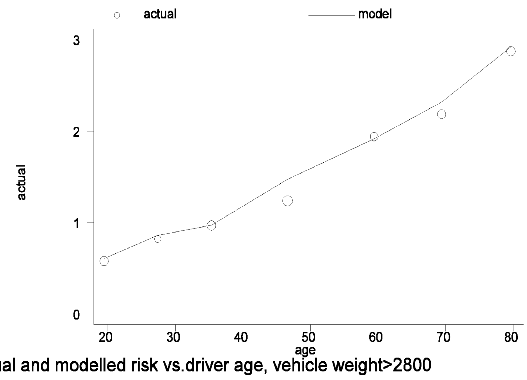
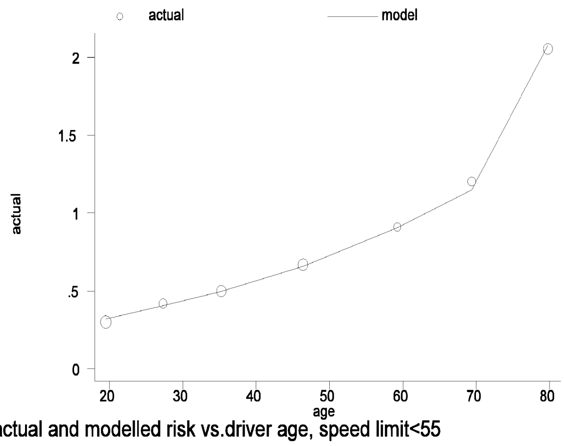
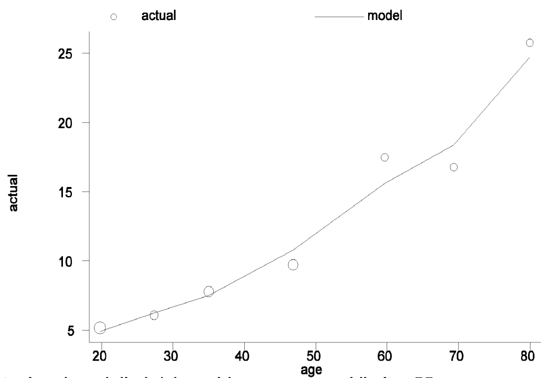


Figure 2.1.2-12 Actual and modelled driver fatality risk (per 1,000 involvements) in cars with frontal impact in car-car collisions versus driver age. Car weight > 2,800 lb. Study cars with no air bags.



actual and modelled risk vs.driver age, speed limit<55

Figure 2.1.2-13 Actual and modelled driver fatality risk (per 1,000 involvements) in cars with frontal impact in car-car collisions versus driver age. Speed limit < 55 mph. Study cars with no air bags.



actual and modelled risk vs.driver age, speed limit>=55

Figure 2.1.2-14 Actual and modelled driver fatality risk (per 1,000 involvements) in cars with frontal impact in car-car collisions versus driver age. Speed limit > =55 mph. Study cars with no air bags.

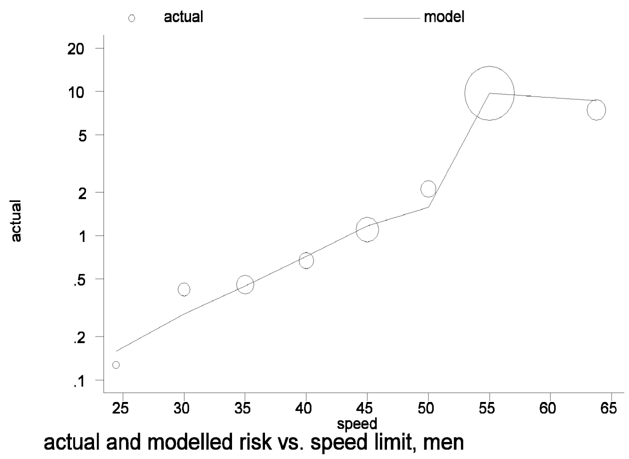


Figure 2.1.2-15 Actual and modelled driver fatality risk (per 1,000 involvements) in cars with frontal impact in car-car collisions versus speed limit. Male drivers. Study cars with no air bags. Logarithmic scale for risk.

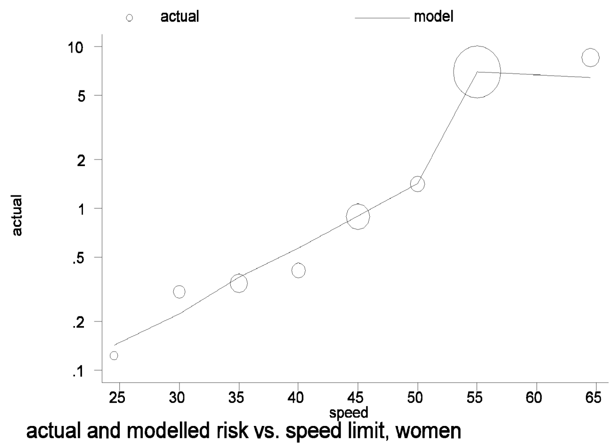


Figure 2.1.2-16 Actual and modelled driver fatality risk (per 1,000 involvements) in cars with frontal impact in car-car collisions versus speed limit. Female driver. Study cars with no air bags. Logarithmic scale for risk.

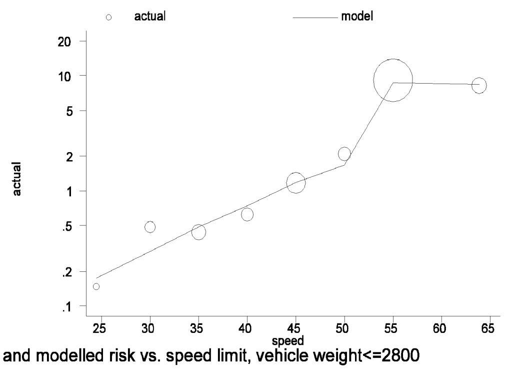


Figure 2.1.2-17 Actual and modelled driver fatality risk (per 1,000 involvements) in cars with frontal impact in car-car collisions versus speed limit. Car weight < =2,800 lb. Study cars with no air bags. Logarithmic scale for risk.

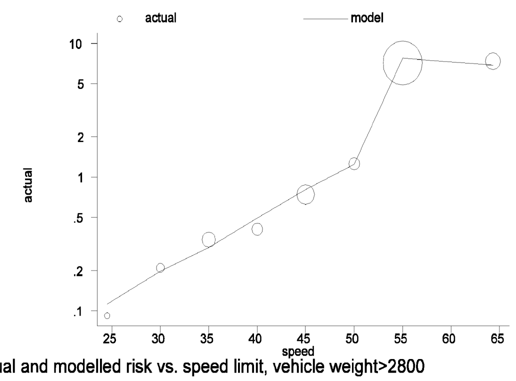
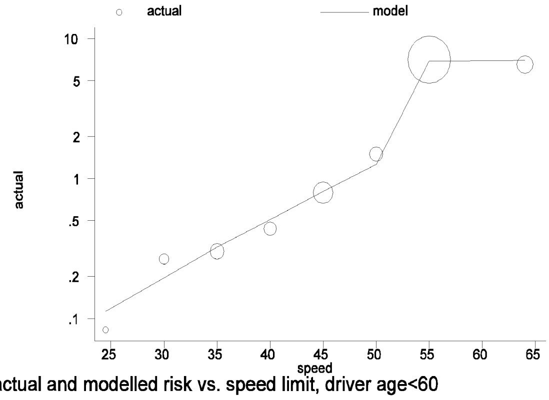
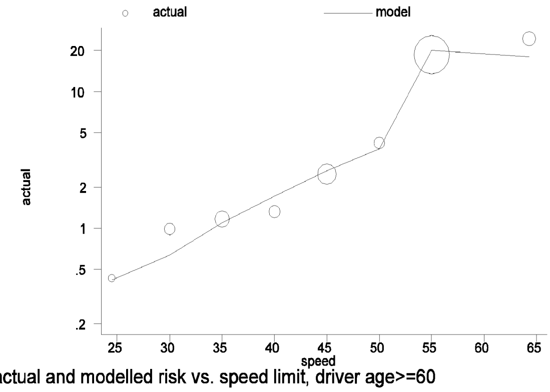


Figure 2.1.2-18 Actual and modelled driver fatality risk (per 1,000 involvements) in cars with frontal impact in car-car collisions versus speed limit. Car weight > 2,800 lb. Study cars with no air bags. Logarithmic scale for risk.



actual and modelled risk vs. speed limit, driver age<60

Figure 2.1.2-19 Actual and modelled driver fatality risk (per 1,000 involvements) in cars with frontal impact in car-car collisions versus speed limit. Driver age < 60 years. Study cars with no air bags. Logarithmic scale for risk.



actual and modelled risk vs. speed limit, driver age>=60

Figure 2.1.2-20 Actual and modelled driver fatality risk (per 1,000 involvements) in cars with frontal impact in car-car collisions versus speed limit. Driver age > =60 years. Study cars with no air bags. Logarithmic scale for risk.

Table 2.1.2-3 Air bag effect in a car with frontal impact, colliding with another car (percent reduction of driver deaths). Non-standard errors in parentheses.

estimate	cars with air bags	cars with only driver air bags
reduction of total deaths	46 (5)	40 (5)
average of reduction of fatality risks	52 (6)	45 (6)

Table 2.1.2-3 shows the resulting estimates. The average reduction of the fatality risk is greater than the reduction of total deaths, suggesting that the effect is smaller in high risk cases. A closer look at Figure 2.2.2-22 shows indeed that the points for predicted risks above 2/1,000 are closer to the line representing equality, showing lower air bag effectiveness, that those for predicted risks below 2/1,000.

A comparison with Table 2.1.1-3 shows that the effects in cars with frontal impacts are greater than in all cars in car-car collisions; it is surprising that the difference is not greater.

Figure 2.1.2-23 shows the actual fatality risks in cars with air bags, and those modelled for cars without air bags versus car weight. Those in cars with air bags are much lower, except for the lightest cars where they are just slightly lower. Figure 2.1.2-24 shows the ratio actual/modelled risk.

Overall, a decreasing (indicating an increasing effect of air bags) trend with car weight is suggested. However, it depends strongly on the single point for the lightest cars. If one ignores it, no clear trend is recognizable, however the point for cars around 3,500 lb shows a very large air bag effect (a more than 60% reduction of the fatality risk).

Figures 2.1.2-25 through 30 show the ratios of actual to predicted risks versus car weight for separately for low and high values of some factors. For speed limits under 55 mph, (Figure 2.1.2-25) no relation between the risk ratio and car weight appears. For higher speed limits (Figure 2.1.2-26) air bag effectiveness appears to increase with car weight. If one ignores the point for the lightest cars, the suggestion of a trend is weaker, but the effect for cars above 3,200 lb could be higher. With regard to driver age (Figure 2.1.2-27 and 28), for younger drivers the air bag effect seems to increase with age, for older drivers the data scatters more, possibly indicating an air bag effect declining with car weight.

Figures 2.1.2-21 and 22 show the actual driver fatality rates in air bag cars versus those predicted for cars without air bags from the model described in Table 2.1.2-2.

The risks in air bag cars are clearly lower and Figure 2.1.2-22 with the logarithmic scales suggests that they are lower by a constant factor, independent of the predicted risk.

To quantify the air bag effect, we proceeded as in section 2.1.1. One estimate is based on dividing the actual number of driver deaths in air bag cars by the sum (properly weighted) of the risks predicted by the model for cars without air bags. The other estimates is based on calculating for each case (actual-predicted)/predicted, and sum (properly weighted) over all cases. “Actual” is 0 or 1, depending on whether the driver survived or died.

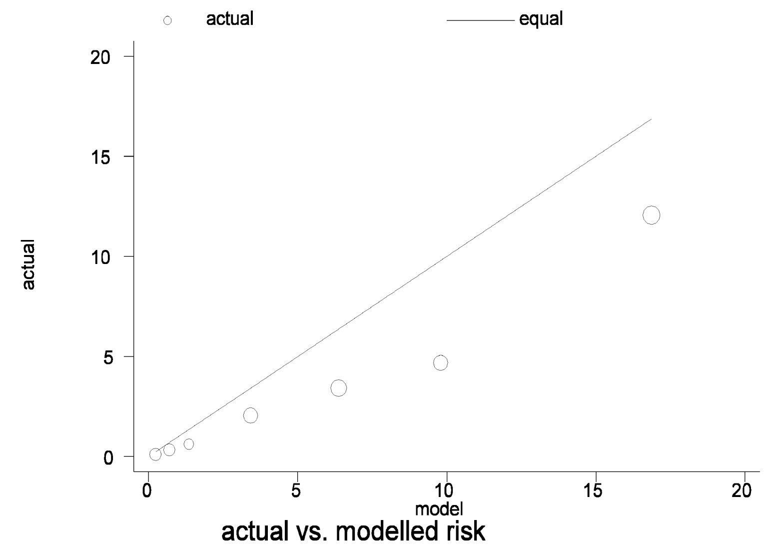


Figure 2.1.2-21 Actual driver fatality risk (per 1,000 involvements) in cars with air bags versus risks predicted from model for cars without air bags. Car-car collisions with frontal impact on the study car. The line represents equality of the actual and predicted risks.

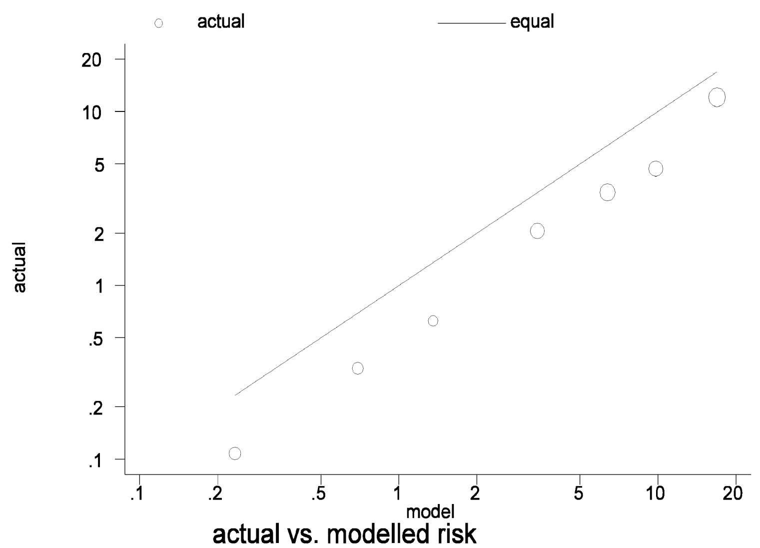


Figure 2.1.2-22 Actual driver fatality risk (per 1,000 involvements) in cars with air bags versus risks predicted from model for cars without air bags. Car-car collisions with frontal impact on the study car. The line represents equality of the actual and predicted risks. Logarithmic scales for both risks.

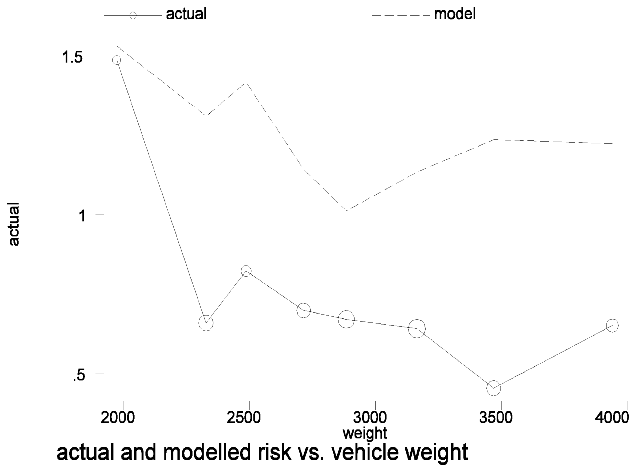


Figure 2.1.2-23 Actual driver fatality risk (per 1,000 involvements) in cars with air bags, and the corresponding risk predicted for non-air bag cars versus car weight. Collisions between two cars with frontal impact on the study car.

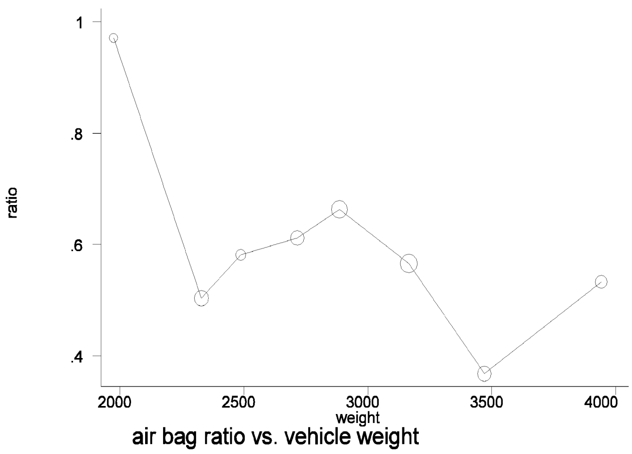


Figure 2.1.2-24 Ratio of the actual driver fatality risk (per 1,000 involvements) in cars with air bags to that expected for cars without air bags versus car weight. Collisions between two cars with frontal impact on the study car.

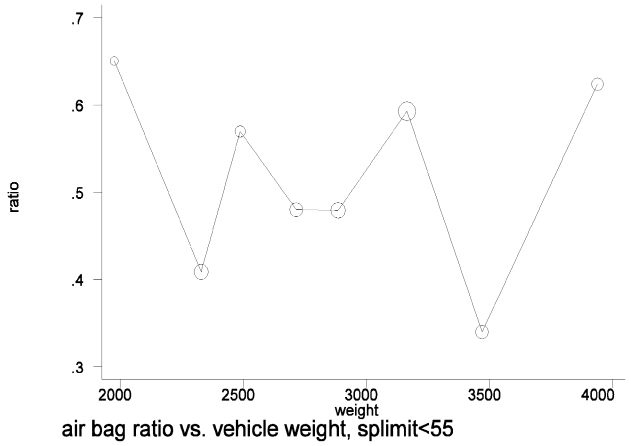


Figure 2.1.2-25 Ratio of the actual driver fatality risk (per 1,000 involvements) in cars with air bags to that expected for cars without air bags versus car weight. Speed limit < 55 mph. Collisions between two cars with frontal impact on the study car.

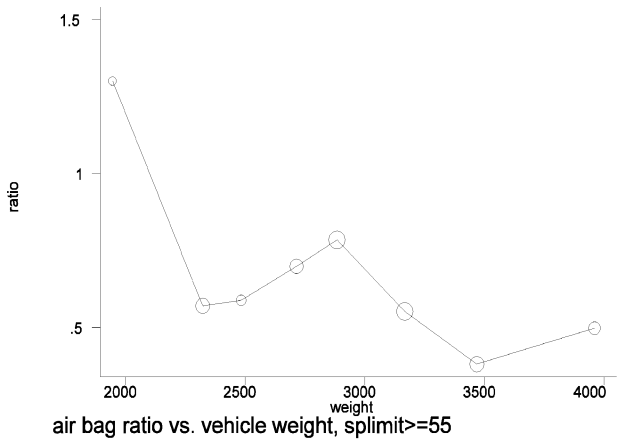


Figure 2.1.2-26 Ratio of the actual driver fatality risk (per 1,000 involvements) in cars with air bags to that expected for cars without air bags versus car weight. Speed limit > = 55 mph. Collisions between two cars with frontal impact on the study car.

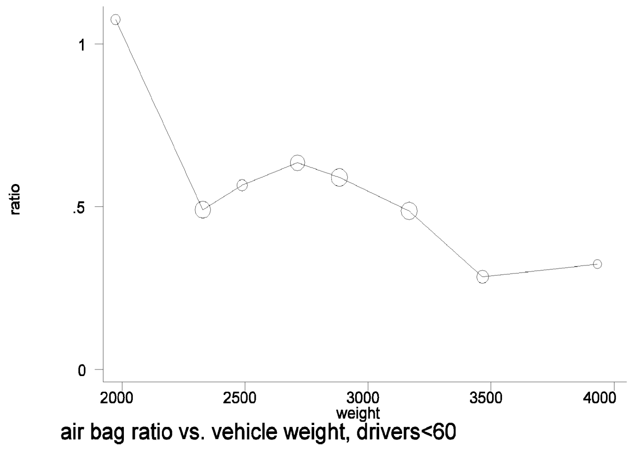


Figure 2.1.2-27 Ratio of the actual driver fatality risk (per 1,000 involvements) in cars with air bags to that expected for cars without air bags versus car weight. Driver age < 60 years. Collisions between two cars with frontal impact on the study car.

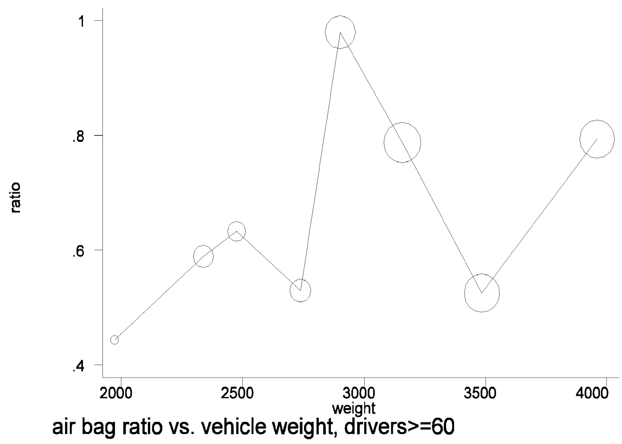


Figure 2.1.2-28 Ratio of the actual driver fatality risk (per 1,000 involvements) in cars with air bags to that expected for cars without air bags versus car weight. Driver age > = 60 years. Collisions between two cars with frontal impact on the study car.

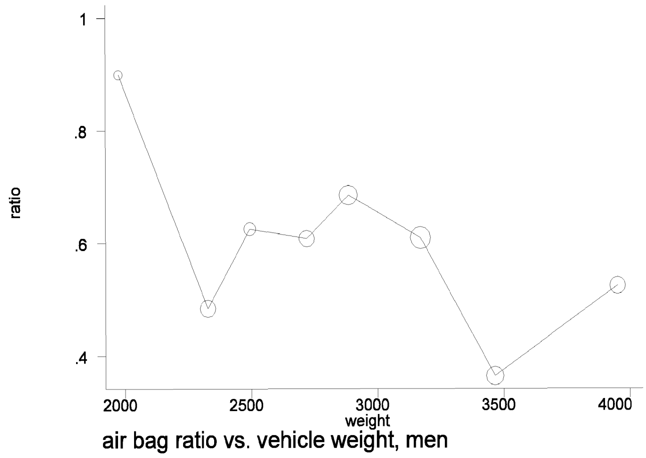


Figure 2.1.2-29 Ratio of the actual driver fatality risk (per 1,000 involvements) in cars with air bags to that expected for cars without air bags versus car weight. Male driver. Collisions between two cars with frontal impact on the study car.

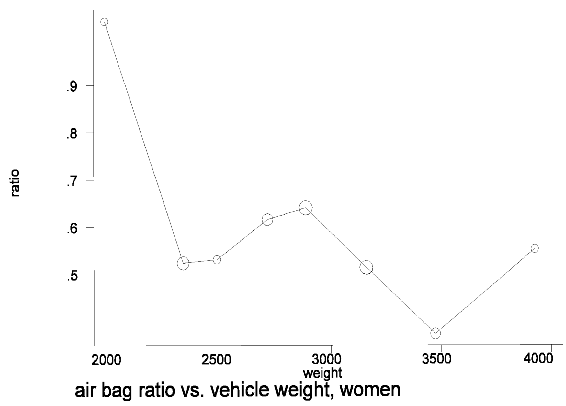


Figure 2.1.2-30 Ratio of the actual driver fatality risk (per 1,000 involvements) in cars with air bags to that expected for cars without air bags versus car weight. Female driver. Collisions between two cars with frontal impact on the study car.

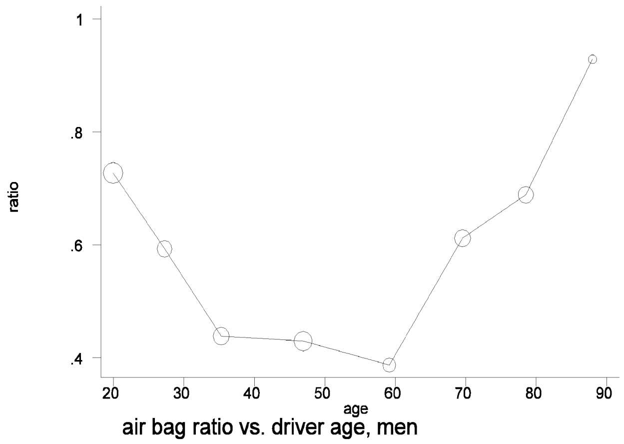


Figure 2.1.2-31 Ratio of the actual driver fatality risk (per 1,000 involvements) in cars with air bags to that expected for cars without air bags versus driver age. Male driver. Collisions between two cars with frontal impact on the study car.

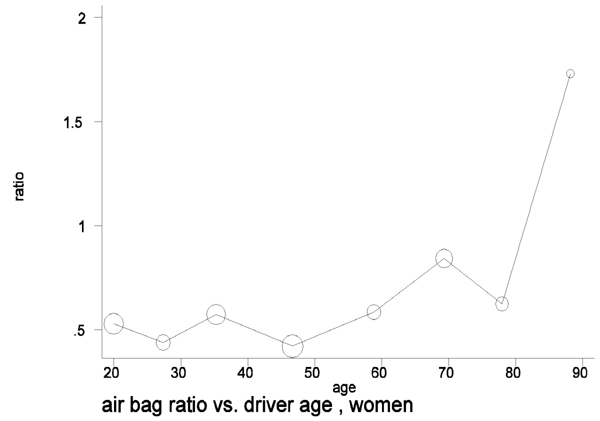


Figure 2.1.2-32 Ratio of the actual driver fatality risk (per 1,000 involvements) in cars with air bags to that expected for cars without air bags versus driver age. Female driver. Collisions between two cars with frontal impact on the study car.

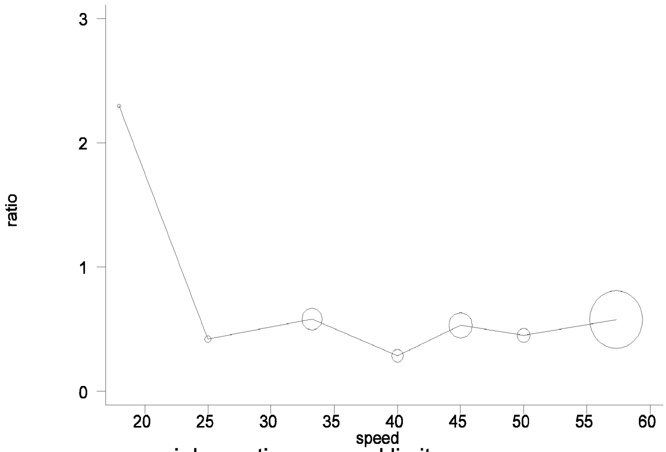


Figure 2.1.2-33 Ratio of the actual driver fatality risk (per 1,000 involvements) in cars with air bags to that expected for cars without air bags versus speed limit. Collisions between two cars with frontal impact on the study car.

For men and women (Figure 2.1.2-29 and 30), the relations between the risk ratio and car weight are very similar; but they show no clear trend with car weight.

Figures 2.1.2-31 and 32 show the risk ratios versus driver age separately for men and women. In both cases, air bag effectiveness declines with age (for the oldest women, even a negative effect of the air bag appears, but this point is based on few cases). Beyond that, the two graphs differ much: for men the air bag effect increases up to 35 years, for women it is practically constant.

Figure 2.1.2-33 shows the risk ratio versus speed limit. Except for speed limits below 25 mph, represented by very few cases, air bag effectiveness does not seem to vary with the speed limit.

To explore this further, we used (actual - predicted)/predicted for each case as dependent variable and run many exploratory regressions. The single factor appearing consistently was "female". The best single model is model 1 shows in Table 2.1.2-4; it also includes an interaction term of female and driver age, showing that air bag effectiveness decreases for women with age. Figure 2.1.2-31 suggests that adding age terms for male drivers might also improve the model, but we considered this as complicated and did not explore it further.

The next factor which entered the model was an interaction female and speed limit (model 2), but it was not "significant" by conventional standards; its inclusion did practically not change the coefficients of model 1.

Table 2.1.2-4 Coefficients of model for air bag effectiveness in cars with frontal impact in collisions between two cars. A negative sign indicates a beneficial effect. Non-standard error are in parentheses.

variables	coefficients	
	model 1	model 2
female	-.19 (.06)	-.20 (.07)
female ∗ (age-30)/10	.07 (.03)	.07 (.03)
female ∗ (splimit=55)		.15 (.07)
constant	-.44 (.09)	-.44 (.05)

Table 2.1.2-5 shows air bag effectiveness in relation to some pre-crash factors. It is interesting that the overall effects for men and women are equal, but that the average effective for women is higher. This would indicate than women get into more "severe" accidents than men. This could be due to women driving lighter cars which implies a higher fatality risk.

With regard to driver age, the estimates for younger and older drivers are very similar, except estimate E2 for all cars with air bags. With regard to car weight, there is no clear pattern. The air bag effect is consistently higher for lower speed limits than for higher speed limits. The difference ranging from 8 to 12 percentage points is between half and 80% of the coefficient of the interaction female with speed limit = 55 in model 2. This is of the order of magnitude one would expect.

Table 2.1.2-5 Air bag effects in cars with frontal impacts in car-car collisions (percent reduction of driver deaths), by different levels of pre-crash factors. E1 estimates the reduction of total deaths. E2, the average of the risk reduction calculated for each case. Non-standard error are in parentheses.

subset of cars	cars with air bags		cars with driver air bags only	
	E1	E2	E1	E2
men	45 (6)	44 (7)	39 (6)	37 (8)
women	45 (6)	59 (8)	40 (7)	51 (12)
age <40 years	45 (7)	56 (8)	38 (8)	45 (10)
age >=40 years	46 (5)	46 (8)	41 (7)	45 (9)
car weight <=2,800 lb	41 (7)	52 (8)	41 (8)	49 (11)
car weight >2,800 lb	48 (5)	52 (7)	39 (6)	42 (9)
splimit <55 mph	51 (7)	53 (8)	47 (8)	46 (9)
splimit >= 55 mph	42 (7)	45 (7)	35 (7)	38 (8)

2.1.3 Right side impacts in car-car collisions

If a car is struck on the right side by another car, only in a very severe impact will passenger compartment intrusion directly cause a fatal injury. Usually, the struck vehicle will be decelerated and its direction of travel changes. Consequently, the driver will strike the forward interior of the passenger compartment. If an air bag deploys in such a crash, it can reduce injury severity and the fatality risk. Right side impacts on the study car were identified by a FARS impact code “3" or a GES impact code “2". To exclude sideswipes as far as possible, only cases where the other car struck with its front were used. That were those with the frontal impact code of “12" in FARS, or “1" in GES.

Table 2.1.3-1 shows the number of study cars involved in such collisions. A very crude estimate of air bag effectiveness is provided by the cross-product ratio of the case numbers, 0.53. It corresponds to a fatality risk reduction of 47%. This simplistic estimate, however, ignores the varying weights of the GES cases, and the effects of confounding factors which might be correlated with the presence or absence of an air bag. The better controlled estimate shown in Table 2.1.3-3 is only 29%.

Table 2.1.3-1 Numbers of study cars in collisions where the front of another car strikes the right side of the study car.

cars with	FARS	GES
no air bag	1,039	5,193
air bags	320	3,008

Table 2.1.3-2 shows the coefficients of the model for the fatality risk in cars without air bags which represented the data quite well. All of the terms would be considered “significant” by conventional standards, with the exception of the term for women, and the age term for women. The term for women was retained, because it appears consistently in most models for different crash configurations, thus suggesting a real effect. The age term for women was retained because it improves the representation of the age-risk relation - an initial slight decrease of the risk with age, followed by a fairly early, stronger increase with increasing age - visibly. For men, the age-risk relation is practically flat in the younger years, and begins to rise at a later age, but more rapidly than for women.

Table 2.1.3-2 Model coefficients for the driver fatality risk in cars without air bags, struck on the right side of the occupant compartment by the front of another car.

variable	coefficient	non-standard error
(splimit -50)/10	.84	.14
splimit =55	1.18	.33
splimit >55	1.03	.40
log(weight/2,800)	-1.56	.36
log(weight/2,100) ∗ (weight <2,100)	-2.70	1.22
(age -60) ∗ (splimit -55)/100	-.067	.026
(age -50) ∗ (age >50) ∗ (weight >2,800)/10	-.20	-.09
female	-.17	.12
female ∗ (age -30)/10	-.15	.09
male ∗ (age -55) ∗ (age >55)/10	.63	.12
female ∗ (age -45) ∗ (age >45)/10	.54	.21
(year - 1990)/10	-.55	.21
constant	-6.03	.23

Figure 2.1.3-1 shows the relation between the actual and the modelled driver fatality risks. The agreement is very good. The relation between car weight and risk is well represented, Figure 2.1.3-2; even if the cases are separated into low and high speed limit, (Figures 2.1.3-3 and 4), young and old drivers, (Figures 2.1.3-5 and 6), but slightly less well for men, Figure 2.1.3-7, than for women, Figure 2.1.3-8. All relations between risk and driver age, (Figures 2.1.3-9 through 14), are well represented by the model. Overall, the relations between the risk and speed limit (Figures 2.4-16 through 21) are well represented, with the exception of the points at 25 mph, where the model always over-predicts, and the points for speed limits over 55 where the model over-predicts for men and under-predicts for women.

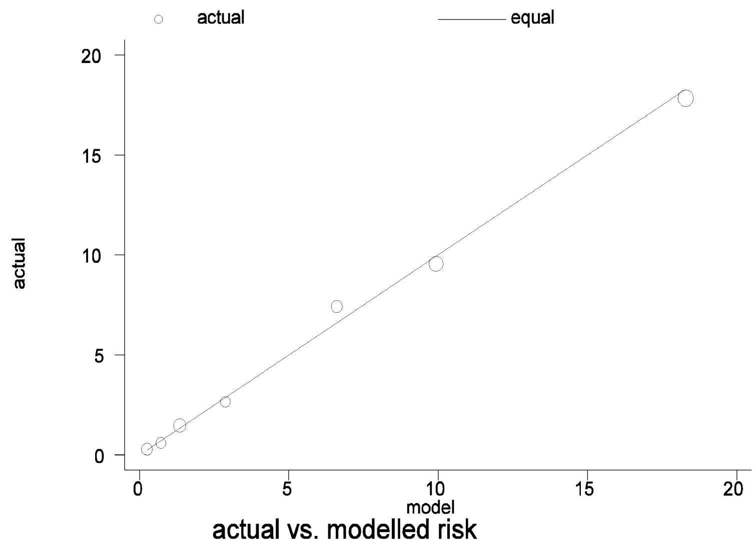


Figure 2.1.3-1 Actual versus modelled driver fatality risk (per 1,000 involvements) in car-car collisions. Right side impacted by front of other car. Study car without air bags.

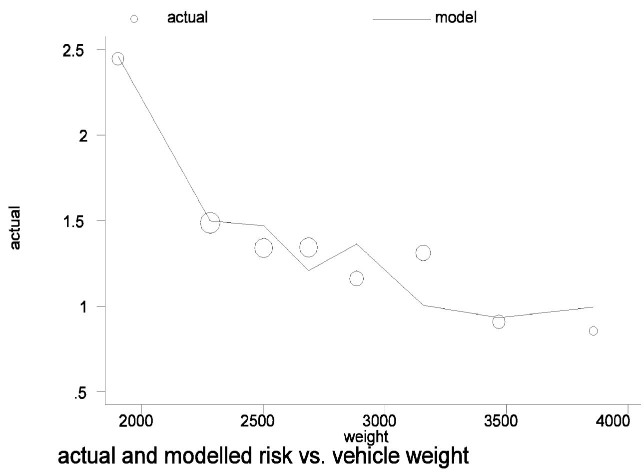


Figure 2.1.3-2 Actual and modelled driver fatality risk in car-car collisions versus weight of study car. Right side impacted by front of other car. Study cars without air bags.

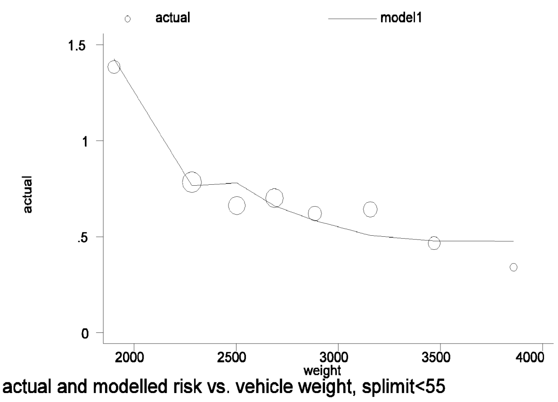


Figure 2.1.3-3 Actual and modelled driver fatality risk in car-car collisions versus weight of study car. Speed limit <55 mph. Right side impacted by front of other car. Study cars without air bags.

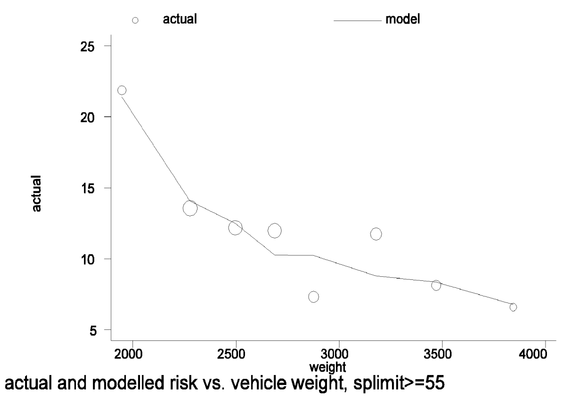
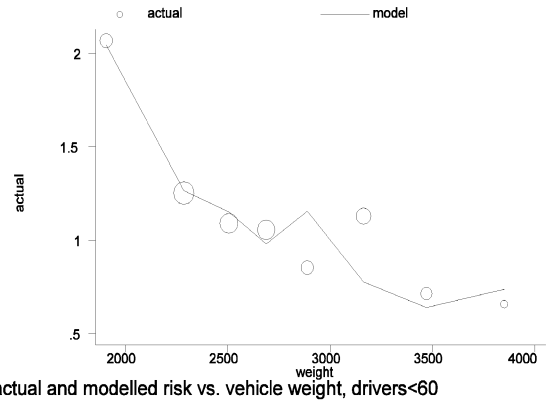
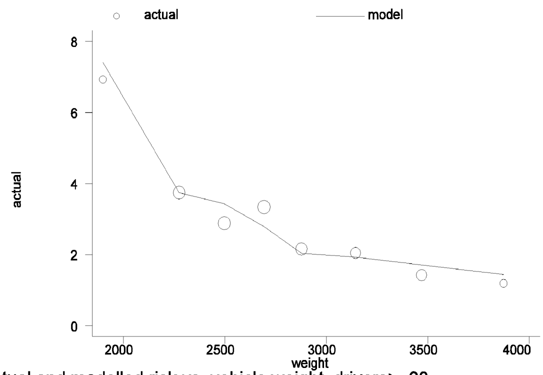


Figure 2.1.3-4 Actual and modelled driver fatality risk in car-car collisions versus weight of study car. Speed limit > =55 mph. Right side impacted by front of other car. Study cars without air bags.



actual and modelled risk vs. vehicle weight, drivers<60

Figure 2.1.3-5 Actual and modelled driver fatality risk in car-car collisions versus weight of study car. Driver age < 60 years. Right side impacted by front of other car. Study cars without air bags.



actual and modelled risk vs. vehicle weight, drivers>=60

Figure 2.1.3-6 Actual and modelled driver fatality risk in car-car collisions versus weight of study car. Driver age > = 60 years. Right side impacted by front of other car. Study cars without air bags.

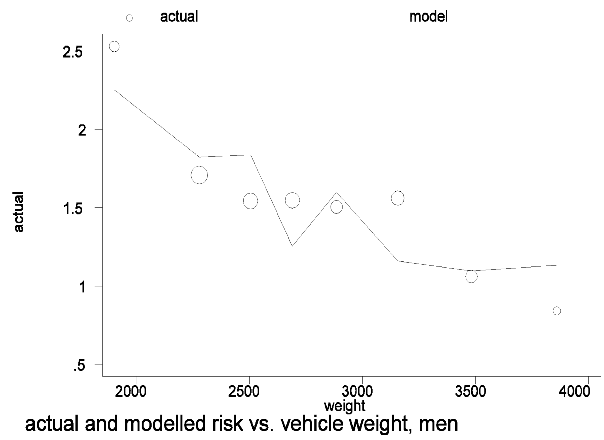


Figure 2.1.3-7 Actual and modelled driver fatality risk in car-car collisions versus weight of study car. Male drivers. Right side impacted by front of other car. Study cars without air bags.

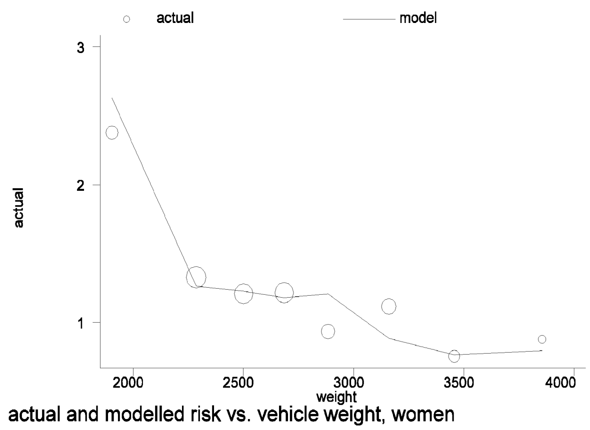


Figure 2.1.3-8 Actual and modelled driver fatality risk in car-car collisions versus weight of study car. Female drivers. Right side impacted by front of other car. Study cars without air bags.

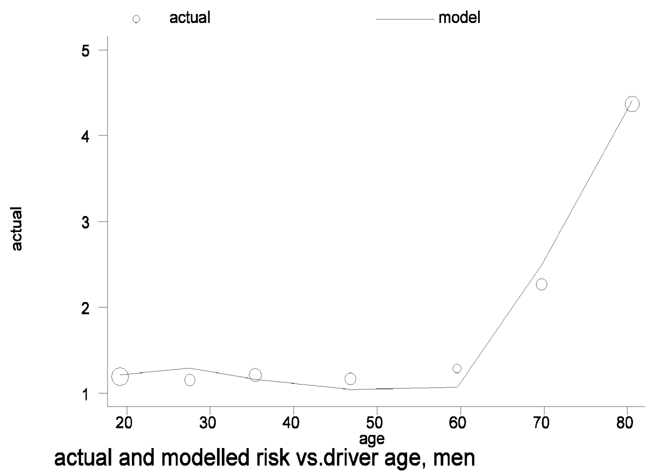


Figure 2.1.3-9 Actual and modelled driver fatality risk in car-car collisions versus driver age. Male Driver. Right side impacted by front of other car. Study cars without air bags.

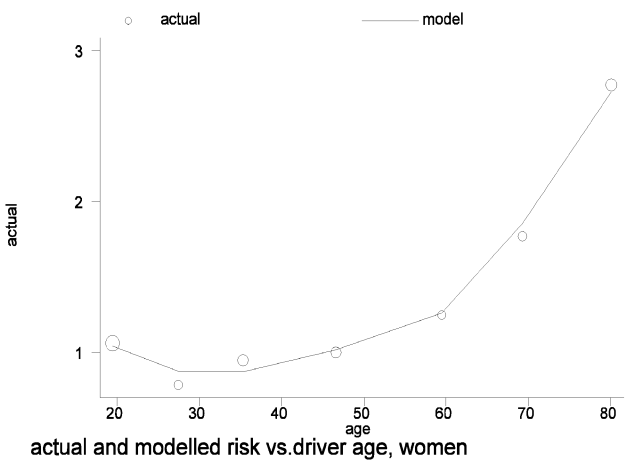


Figure 2.1.3-10 Actual and modelled driver fatality risk in car-car collisions versus driver age. Female driver. Right side impacted by front of other car. Study cars without air bags.

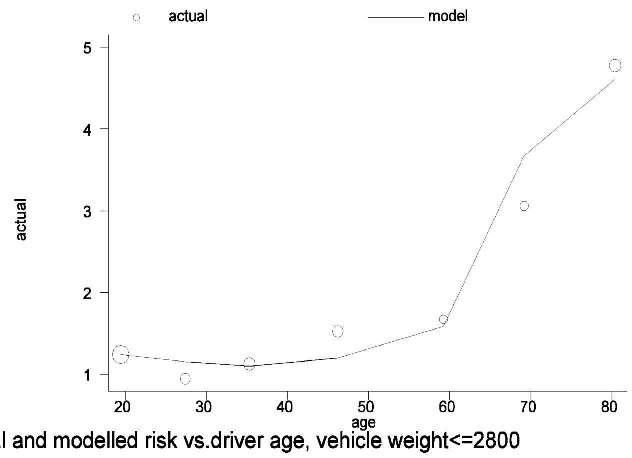


Figure 2.1.3-11 Actual and modelled driver fatality risk in car-car collisions versus driver age. Car weight < =2,800 lb. Right side impacted by front of other car. Study cars without air bags.

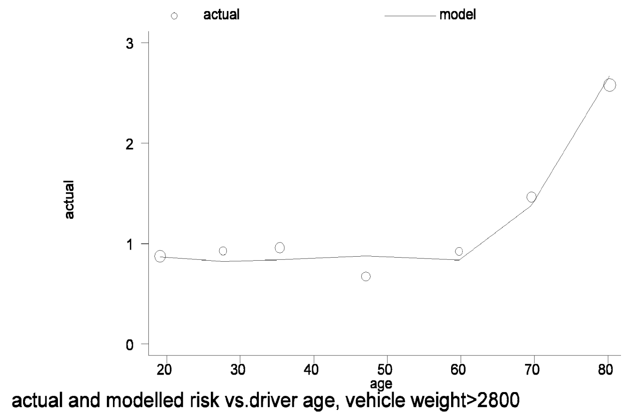


Figure 2.1.3-12 Actual and modelled driver fatality risk in car-car collisions versus driver age. Car weight > 2,800 lb. Right side impacted by front of other car. Study cars without air bags.

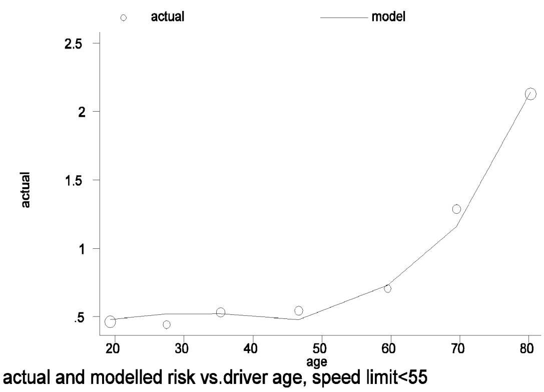


Figure 2.1.3-13 Actual and modelled driver fatality risk in car-car collisions versus driver age. Speed limit <55 mph. Right side impacted by front of other car. Study cars without air bags.

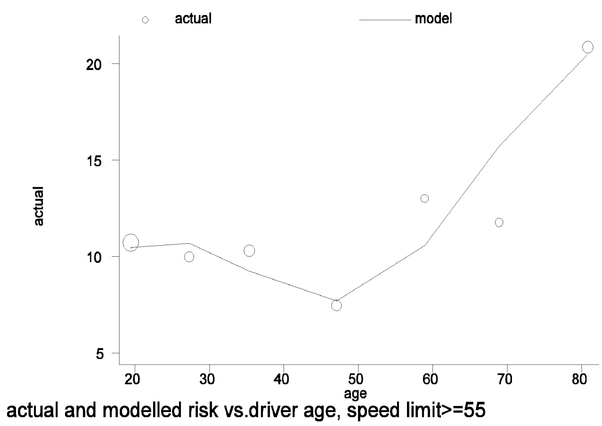


Figure 2.1.3-14 Actual and modelled driver fatality risk in car-car collisions versus weight of study car. Driver age. Speed limit > =55 mph. Right side impacted by front of other car. Study cars without air bags.

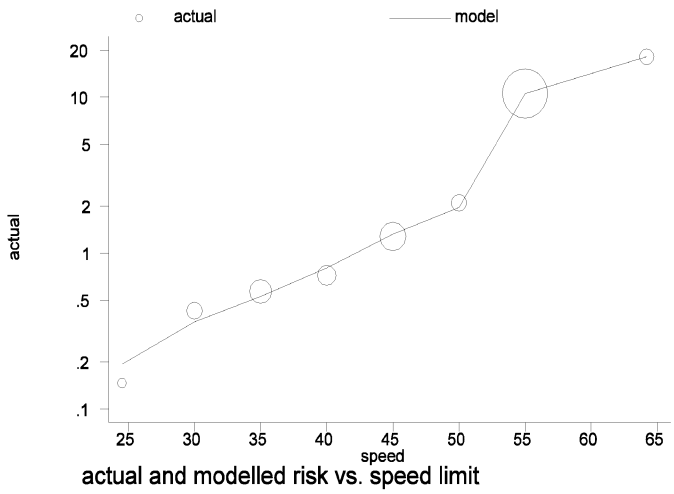


Figure 2.1.3-15 Actual and modelled driver fatality risk in car-car collisions versus speed limit. Right side impacted by front of other car. Study cars without air bags.

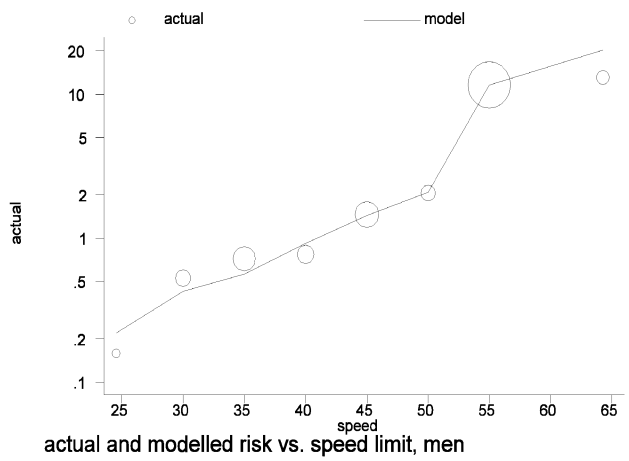


Figure 2.1.3-16 Actual and modelled driver fatality risk in car-car collisions versus speed limit. Male driver. Right side impacted by front of other car. Study cars without air bags.

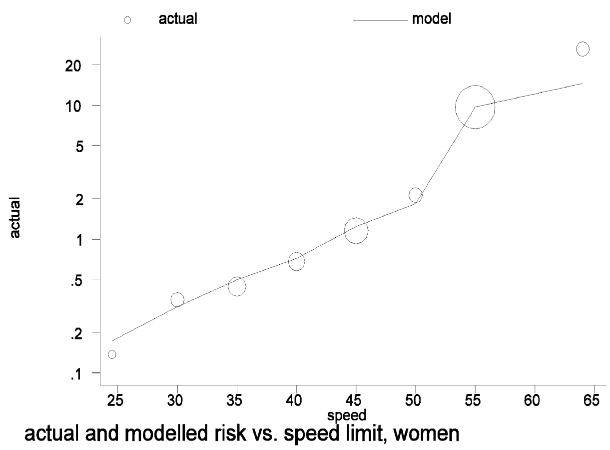
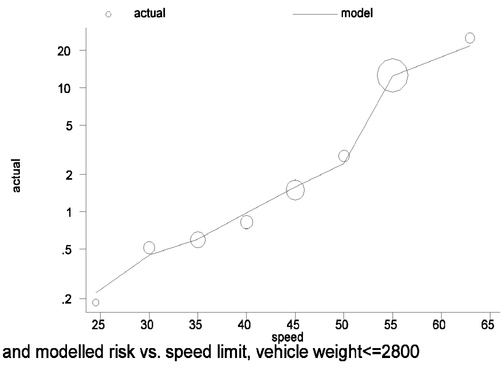
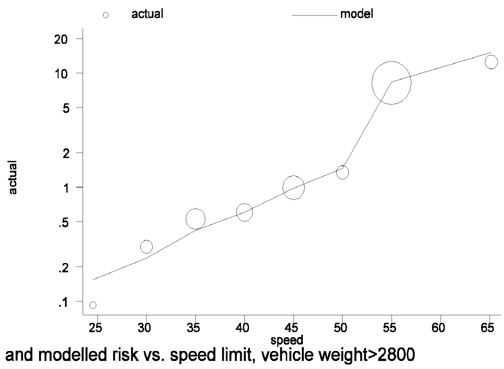


Figure 2.1.3-17 Actual and modelled driver fatality risk in car-car collisions versus speed limit. Female driver. Right side impacted by front of other car. Study cars without air bags.



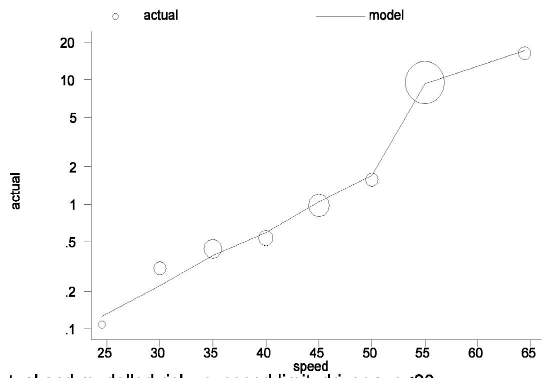
actual and modelled risk vs. speed limit, vehicle weight<=2800

Figure 2.1.3-18 Actual and modelled driver fatality risk in car-car collisions versus speed limit. Car weight < = 2,800 lb. Right side impacted by front of other car. Study cars without air bags.



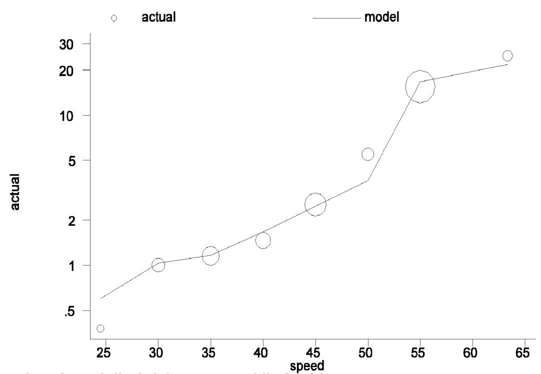
actual and modelled risk vs. speed limit, vehicle weight>2800

Figure 2.1.3-19 Actual and modelled driver fatality risk in car-car collisions versus speed limit. Car weight >2,800 lb. Right side impacted by front of other car. Study cars without air bags.



actual and modelled risk vs. speed limit, driver age<60

Figure 2.1.3-20 Actual and modelled driver fatality risk in car-car collisions versus speed limit of study car. Driver age < 60 years. Right side impacted by front of other car. Study cars without air bags.



actual and modelled risk vs. speed limit, driver age>=60

Figure 2.1.3-21 Actual and modelled driver fatality risk in car-car collisions versus speed limit of study car. Driver age > = 60 years. Right side impacted by front of other car. Study cars without air bags.

To estimate the effects of air bags on the fatality risk, this model was used to predict for the cars with air bags what the risk would have been, if they had not had air bags, and compare these risks with the actual driver deaths. This was done in two different ways: first, total actual deaths were compared with the sum of the risks in all crashes. Comparing them gives the overall air bag effect. The other approach calculated for each case the ratio death/risk, and averaged this ratio over all cases, properly weighted. Table 2.1.3-3 shows the risk reduction thus obtained.

Table 2.1.3-3 Driver fatality risk reduction (percent) in cars with air bags relative to the model for cars without air bags. Collisions between two cars, study car impacted on the right side by the front of the other car. Non-standard errors are in parentheses.

estimated as	cars with air bags	cars with driver air bag only
reduction of total deaths	29 (7)	26 (9)
average reduction of fatality risks	38 (9)	36 (9)

The overall fatality reduction is 29%. It is much lower than the very crude estimates of 47% obtained from Table 2.1.3-1. This shows that weighting of the GES cases and/or control for the confounding factors is necessary. The overall reduction of 29% is lower than the average risk reduction of 38%. This shows that the air bag effect must be less in crashes with higher risks than in crashes with lower risks.

Figures 2.1.3-22 and 23 show the actual risks in cars with air bags versus those predicted for the same cars from the model for cars without air bags. Figure 2.1.3-22 with logarithmic scales suggests that the risk reduction is practically constant, except for the two points with predicted risks of 7 and 11 per 1,000 involvements. For them, there is practically no risk reduction.

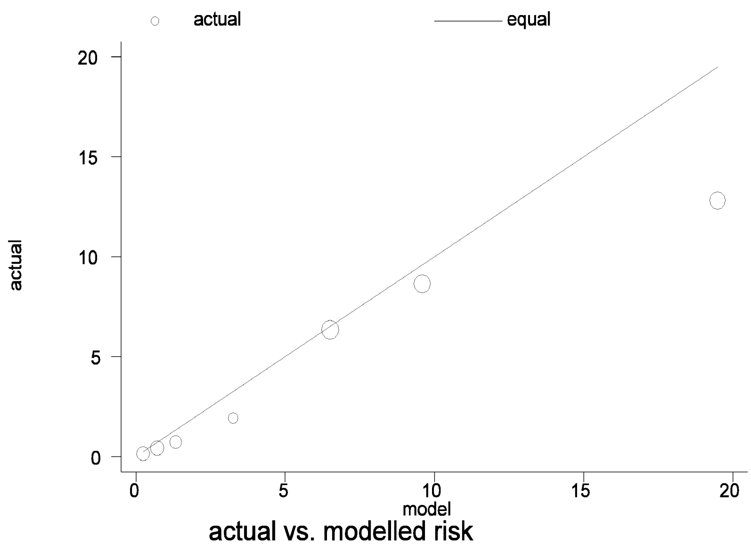


Figure 2.1.3-22 Actual driver fatality risk in cars with air bags versus modelled risk for cars without air bags. Cars struck on the right side by the front of another car.

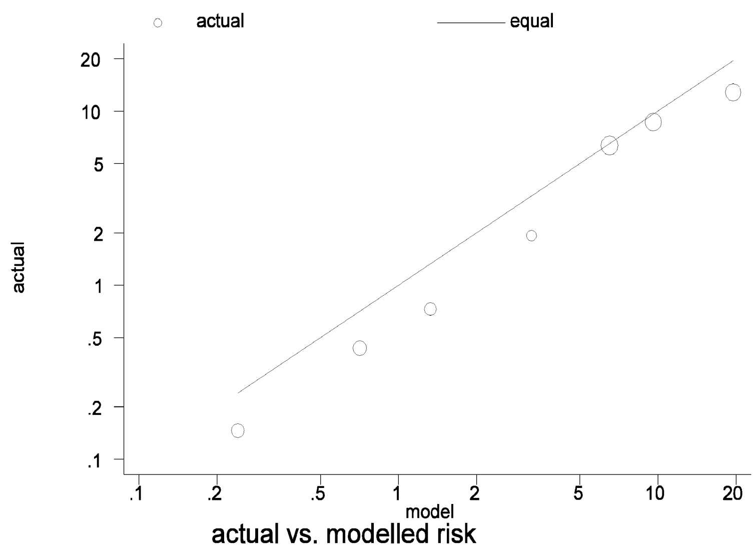


Figure 2.1.3-23 Actual driver fatality risk in cars with air bags versus modelled risk for cars without air bags. Cars struck on the right side by the front of another car. Double logarithmic scales.

To study this further, it was attempted to represent the ratio death/modelled risk as a function of car weight, driver age, speed limit and possibly interactions. This was not successful, presumably because there were only 320 driver deaths in cars with air bags. Therefore, we only generated graphic presentations of air bag effectiveness estimates versus each of the variables used for modelling, and made numerical estimates for low and high values of these variables.

Figure 2.1.3-24 shows the actual risk in cars with air bags, and the risk their drivers would have faced if the cars had not had air bags, versus car weight. While for most weights the actual risks are lower than those expected from the model for cars without air bags, for cars weighing 2,400 to 2,800 lb, the actual risks are slightly higher, but the small differences could also be random. Figure 2.1.3-25 shows the ratio of actual to modelled deaths, reflecting the apparent effect of air bags versus car weight.

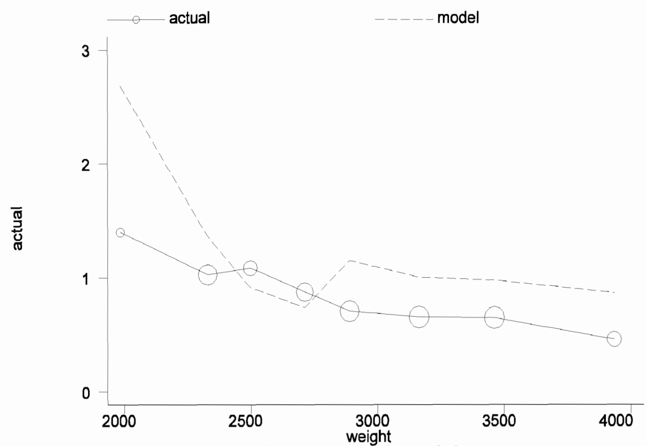
Figures 2.1.3-26 and 27 disaggregate the previous figure by speed limit. For speeds under 55 mph, air bags have a beneficial effect for all weights, or perhaps an effect which increases slightly with weight; for high speeds, there seems to be an approximately constant beneficial effect, whereas between 2,400 and 2,800 lb there appears to be a detrimental effect.

Figures 2.1.3-28 and 29 show the effect versus weight, disaggregated by driver age. Here we see a light detrimental air bag effect between 2,400 and 2,800 lb for younger drivers, but a consistent beneficial effect for older drivers.

Disaggregating by sex, Figures 2.1.3-30 and 31, we see detrimental effects for both men and women in the 2,400 to 2,800 lb range, and for women also in the 2,200-2,400 range.

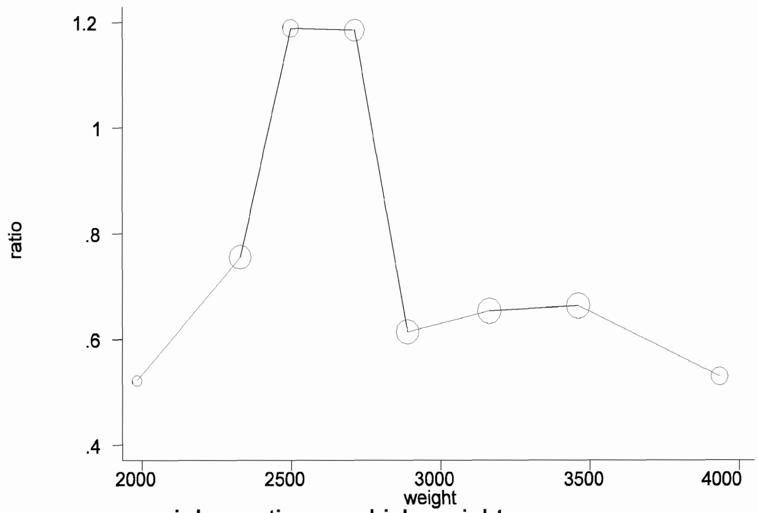
For very young drivers, Figure 2.1.3-32 and 33, air bags have little or no effect, for middle age drivers, they have beneficial effects and for the oldest drivers they seem to have detrimental effects.

With regard to the speed limit, Figure 2.1.3-34, air bags have the smallest effect at speed limits of 55 mph or higher; at lower speed limits there is relatively little variation in the effectiveness. This pattern holds also if one disaggregates the relation.



actual and modelled risk vs. vehicle weight

Figure 2.1.3-24 Actual driver fatality risk in cars with air bags, and risk predicted for cars without air bags versus car weight. Car struck on the right side by the front of another car.



air bag ratio vs. vehicle weight

Figure 2.1.3-25 Ratio of the actual driver fatality risk in cars without air bags to the risk predicted for cars without air bags versus car weight. Car struck on the right side by the front of another car.

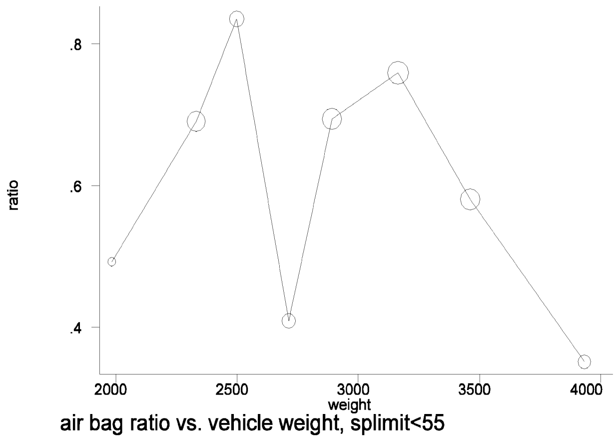


Figure 2.1.3-26 Ratio of the actual driver fatality risk in cars without air bags to the risk predicted for cars without air bags versus car weight. Speed limit <55 mph. Car struck on the right side by the front of another car.

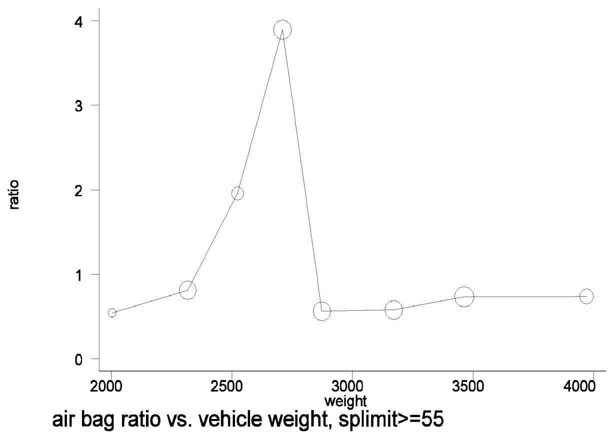


Figure 2.1.3-27 Ratio of the actual driver fatality risk in cars without air bags to the risk predicted for cars without air bags versus car weight. Speed limit >=55 mph. Car struck on the right side by the front of another car.

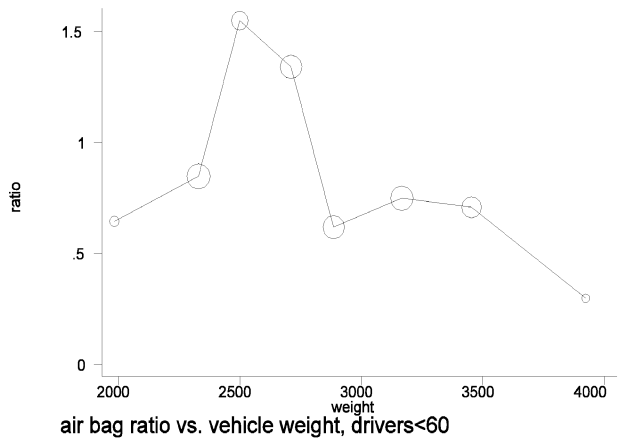


Figure 2.1.3-28 Ratio of the actual driver fatality risk in cars without air bags to the risk predicted for cars without air bags versus car weight. Driver age <60 years. Car struck on the right side by the front of another car.

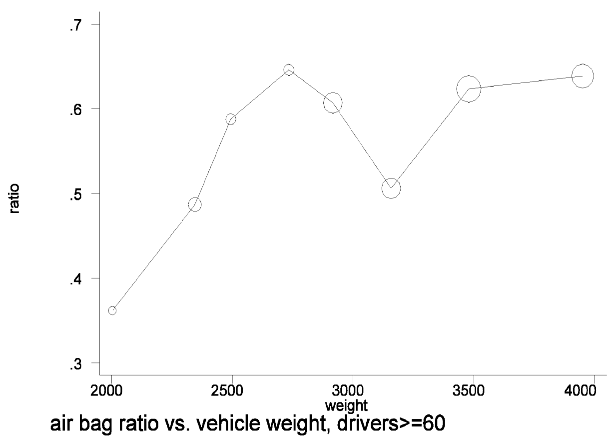


Figure 2.1.3-29 Ratio of the actual driver fatality risk in cars without air bags to the risk predicted for cars without air bags versus car weight. Driver age >=60 years. Car struck on the right side by the front of another car.

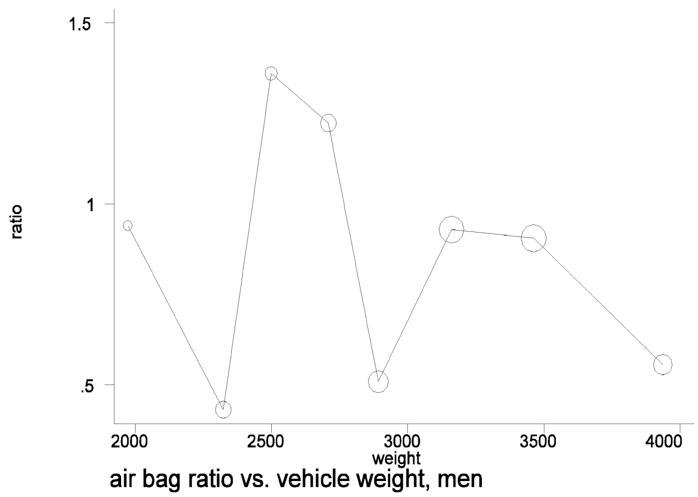


Figure 2.1.3-30 Ratio of the actual driver fatality risk in cars without air bags to the risk predicted for cars without air bags versus car weight. Male drivers. Car struck on the right side by the front of another car.

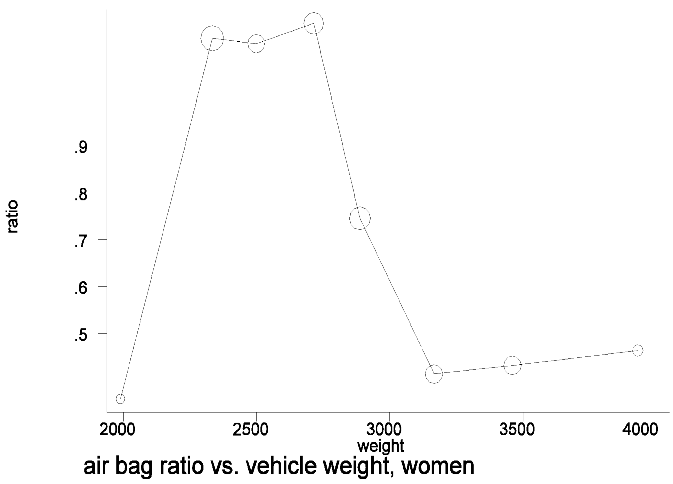


Figure 2.1.3-31 Ratio of the actual driver fatality risk in cars without air bags to the risk predicted for cars without air bags versus car weight. Female drivers. Car struck on the right side by the front of another car.

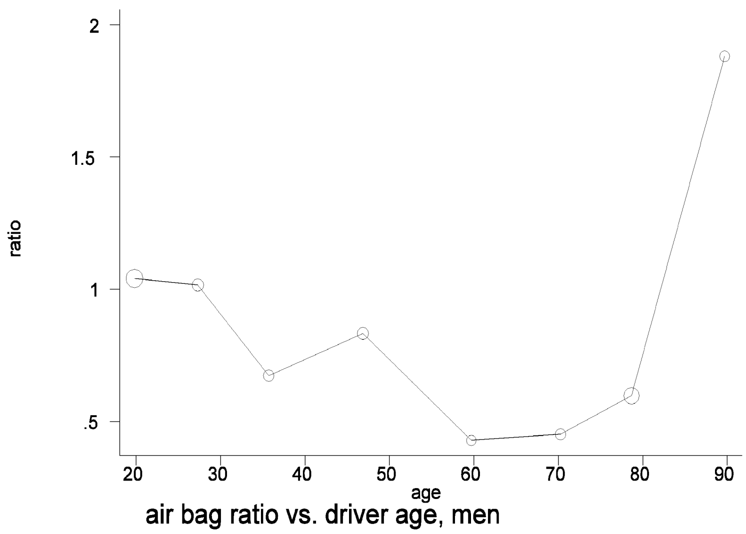


Figure 2.1.3-32 Ratio of the actual driver fatality risk in cars without air bags to the risk predicted for cars without air bags versus driver age. Male drivers. Car struck on the right side by the front of another car.

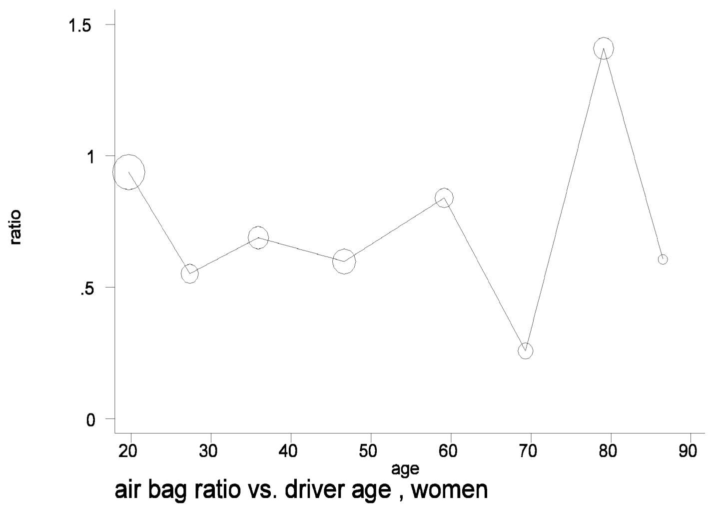


Figure 2.1.3-33 Ratio of the actual driver fatality risk in cars without air bags to the risk predicted for cars without air bags versus driver age. Female drivers. Car struck on the right side by the front of another car.

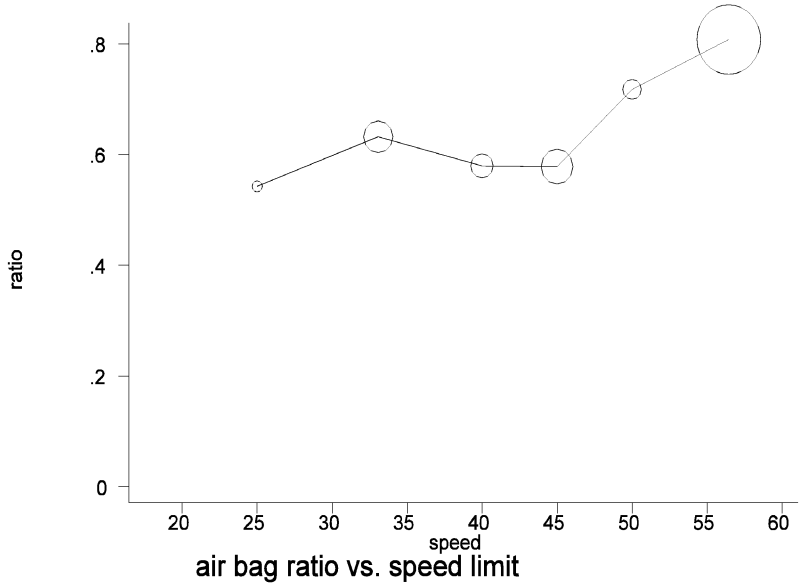


Figure 2.1.3-34 Ratio of the actual driver fatality risk in cars without air bags to the risk predicted for cars without air bags versus speed limit. Car struck on the right side by the front of another car.

Table 2.1.3-4 shows the effectiveness estimates for dichotomies of the variables. There is practically no difference in the effectiveness for men and women. The effectiveness for young drivers, low weights, and high speed limits is low, essentially within the noise level. The large effects for older drivers and high weights may be due to the same underlying factor, because of the correlation between these variables. The large effect for low speed limits must have other reasons, because there is practically no correlation between speed limit and car weight or driver age.

Intriguing is the observation that air bags in cars weighing 2,400 to 2,800 lb seem to have a detrimental effect at high speed limits, and for young drivers. This may be one of the reasons behind the pattern seen in Table 2.1.3-4. A closer examination of crashes involving cars in this weight range would be justified.

Table 2.1.3-4 Driver fatality risk reduction in cars with air bags relative to the model for cars without air bags, in percent. Collisions between two cars, study car impacted on the right side by the front of the other car. E1 are estimates 1 - (actual driver deaths)/(expected driver deaths), E2 are averages of (1-death/risk), calculated for each case. Non-standard errors in parentheses.

subset of cases	E1	E2
men	27 (9)	30 (9)
women	31 (7)	43 (13)
age <40 years	10 (11)	23 (16)
age > =40 years	40 (9)	54 (13)
weight < =2,800 lb	10 (15)	30 (19)
weight > 2,800 lb	37 (7)	59 (9)
speed limit < 55 mph	39 (9)	39 (10)
speed limit > =55 mph	19 (12)	18 (11)

2.1.4 Left side impact in car-car collisions

If a car is struck in the left side of the occupant compartment by another car, driver injuries can be caused by the intrusion of the occupant compartment, as well as by the driver striking the interior of the occupant compartment since the car becomes decelerated and deflected. Air bags may provide some protection against the second effect, if they deploy. However, they provide no protection against the first effect. Therefore, one would expect little if any effect of air bags in such collisions.

Left side impacts on the study car were defined by a FARS impact code "9" which restricts impact to the occupant compartment, or a GES impact code "3" which includes impacts or the entire left side. The effect of this discrepancy has already been discussed. To exclude sideswipes, where the relative motion of the two cars vary widely, only cases where the other vehicle was striking with the front were used; they have for the "other" car the impact codes "12" in FARS, "1" in GES.

Table 2.1.4-1 shows the numbers of study cars in this impact configuration. A very crude estimate of air bag effectiveness is given by the cross-product ratio of 0.69 which corresponds to a fatality risk reduction by 31% which is surprisingly large. However, this very crude estimate ignores the varying weights of the GES cases, and the effects of confounding factors which may differ between cars with and those without air bags. Indeed, estimates controlling for these factors (Table 2.1.4-3) are much lower, 19%.

Table 2.1.4-1 Number of study cars in collisions where the case vehicle was struck on the left side by another car with the front.

cars with	FARS	GES
no air bag	2,112	5,381
air bag	819	3,037

Table 2.1.4-2 shows the coefficients of the model which fitted the data fairly well. By conventional standards, which are not applicable with our modelling approach, all terms would be considered "significant", except possibly that for the calender year. However, because it appears consistently also in models for other crash types, it was retained.

Figure 2.1.4-1 shows the actual driver fatality risks versus those modelled. The overall agreement is excellent.

Table 2.1.4-2 Coefficients of the model for the driver fatality risk (per 1,000 involvements) in cars struck on the left side by the front of another car.

variable	coefficient	non-standard error
(splimit -50)/10	.79	.11
splimit =55	.91	.37
splimit >55	1.41	.44
log(weight/2,800) ∗ (splimit<55)	-1.13	.44
log(weight/2,800) ∗ (splimit > =55)	-1.77	.38
(age-55) ∗ (age>55) ∗ (weight>3,000)/10	-.35	.10
female	-.30	.11
(age-30)/10	.20	.04
(age-60) ∗ (age>60) ∗ male/10	.98	.15
(age-50) ∗ (age>50) ∗ female/10	.59	.12
year -1990	-.06	.03
constant	-5.69	.29

Figure 2.1.4-2 shows the actual and the modelled risks versus vehicle weight. The overall trend is represented, except possibly for the points for the lowest and the highest weights. The differences, however are comparable with the scatter of the other points and may therefore be random. Figures 2.1.4-2 through 8 show the actual and modelled risks versus car weight, disaggregated by other factors. Here the representation of the data is less good, with a large scatter of the data points for speed limits of 55 mph or more, or for male drivers. The point for the lightest cars is not well represented for women, and for young drivers as well as for old drivers. The latter relations, however, are quite well represented except for the points for the lightest vehicles.

Figures 2.1.4-9 and 10 show the actual and modelled risks versus driver age for men and for women. In both cases, the actual data are very well represented by the model. The same holds for disaggregations by car weight and speed limit, which are not shown.

Figure 2.1.4-11 shows the actual and modelled risks versus speed limit. With the exception of the points for the lowest speed limits - if they were combined, the actual risk would be close to the modelled one - the model represent the data well. The pattern is very similar if one disaggregates by driver age, driver sex and car weight (graphs not shown).

The fairly smooth relations between risk and driver age, and risk and speed limit, and the good representation of the data by the model contrasts with the much larger scatter of the points with regard to car weight, and the sometimes possibly systematic deviation between the actual and modelled values. One potential explanation could be that car properties other than weight have a strong effect on the fatality risk in left side impacts. Because each of the data points plotted by weight typically contains very many cases involving the same car model, such effects may not average out, as they could do in the case of points representing groups of drivers, or highways with the same speed limit.

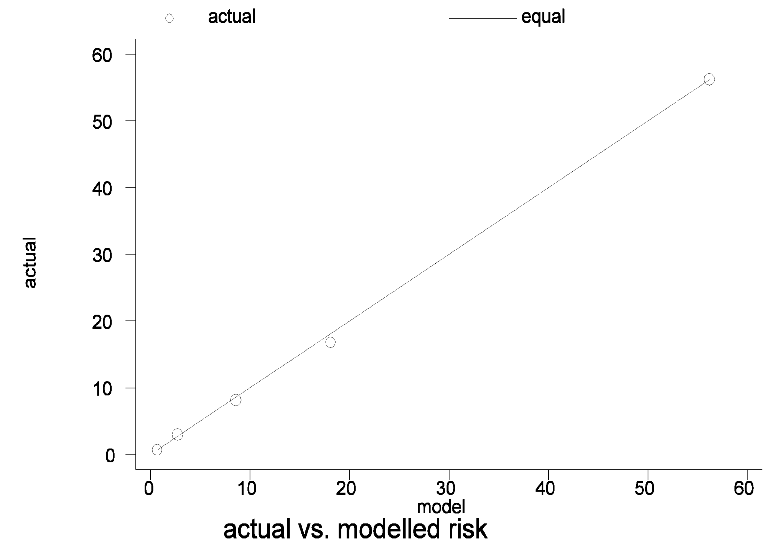


Figure 2.1.4-1 Actual versus modelled driver fatality risk (per 1,000 involvements) in a car without air bags struck on the left side by the front of another car.

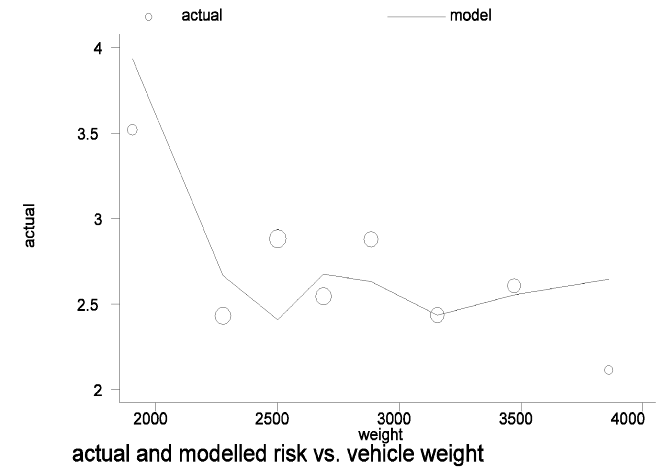
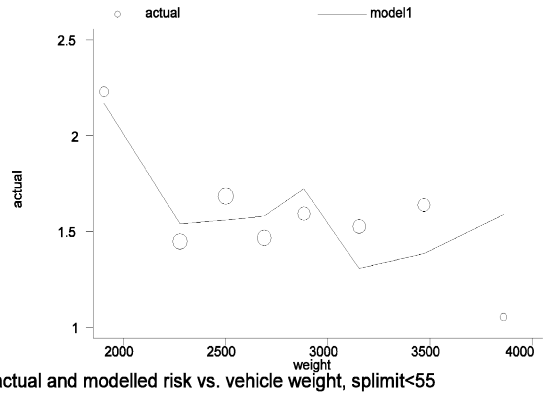
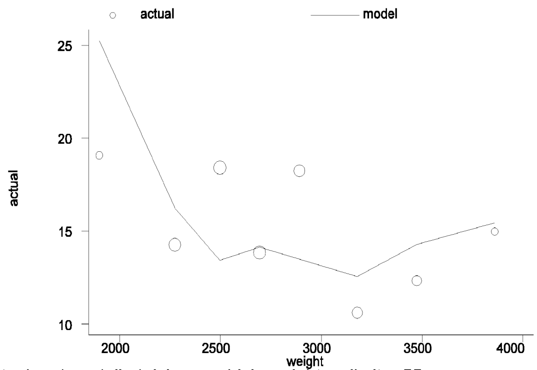


Figure 2.1.4-2 Actual and modelled driver fatality risk (per 1,000 involvements) in cars without air bag struck on the left side by the front of another car versus weight of the case car.



actual and modelled risk vs. vehicle weight, splimit<55

Figure 2.1.4-3 Actual and modelled driver fatality risk (per 1,000 involvements) in cars without air bags struck on the left side by the front of another car versus weight of the case car. Speed limit < 55 mph.



actual and modelled risk vs. vehicle weight, splimit>=55

Figure 2.1.4-4 Actual and modelled driver fatality risk (per 1,000 involvements) in cars without air bags struck on the left side by the front of another car versus weight of the case car. Speed limit > =55 mph.

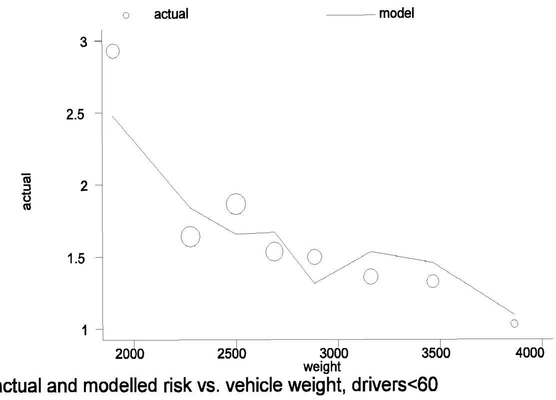


Figure 2.1.4-5 Actual and modelled driver fatality risk (per 1,000 involvements) in cars without air bags struck on the left side by the front of another car versus weight of the case car. Driver age < 60 years.

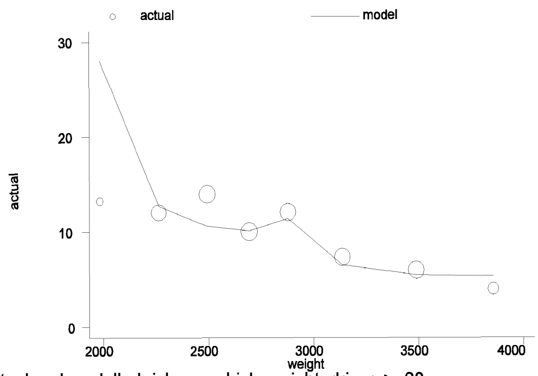


Figure 2.1.4-6 Actual and modelled driver fatality risk (per 1,000 involvements) in cars without air bags struck on the left side by the front of another car versus weight of the case car. Driver age > =60 years.

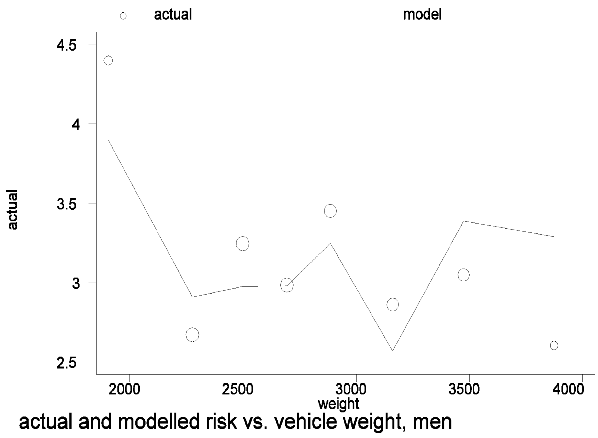


Figure 2.1.4-7 Actual and modelled driver fatality risk (per 1,000 involvements) in cars without air bags struck on the left side by the front of another car versus weight of the case car. Male driver.

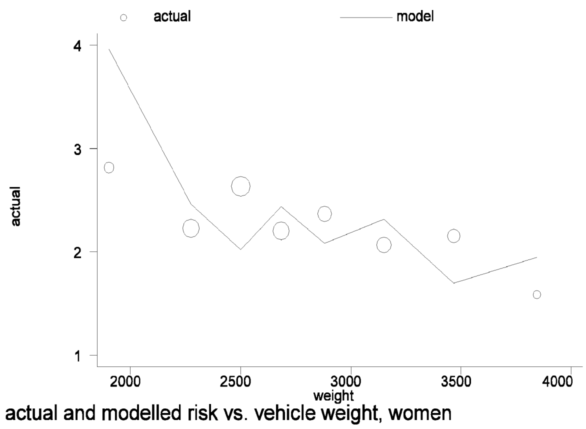


Figure 2.1.4-8 Actual and modelled driver fatality risk (per 1,000 involvements) in cars without air bags struck on the left side by the front of another car versus weight of the case car. Female driver.

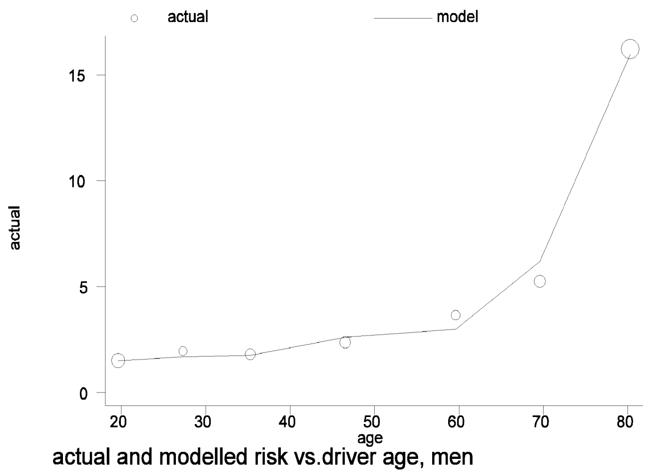


Figure 2.1.4-9 Actual and modelled driver fatality risk (per 1,000 involvements) in cars without air bags struck on the left side by the front of another car versus driver age. Male driver.

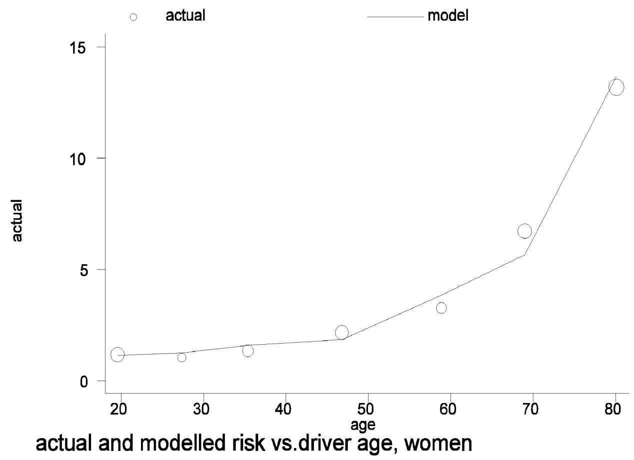


Figure 2.1.4-10 Actual and modelled driver fatality risk (per 1,000 involvements) in cars without air bags struck on the left side by the front of another car versus driver age. Female driver.

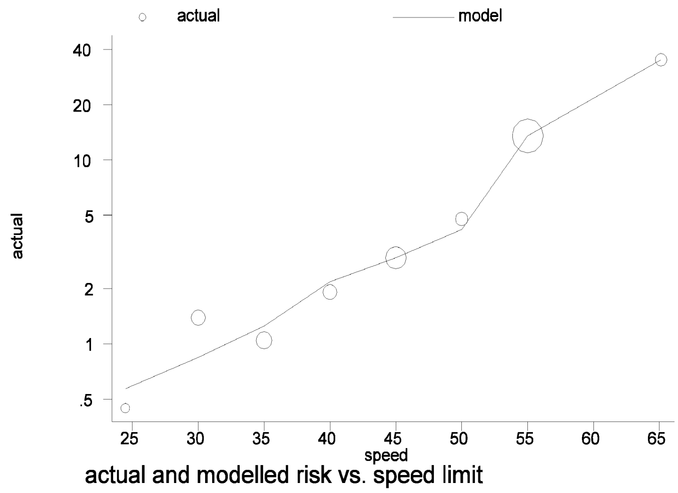


Figure 2.1.4-11 Actual and modelled driver fatality risk (per 1,000 involvements) in cars without air bags struck on the left side by the front of another car versus speed limit. Female driver. Logarithmic scale.

This model was used to predict for the cars with air bags what the driver fatality risk would have been if the cars had not had air bags. Figure 2.1.4-12 shows the actual risks for driver in cars with air bags. It appears that there is an increasing effect of air bags with an increase in the predicted risk. The same data, shows with logarithmic scales in Figure 2.1.4-13 suggest a different pattern: there might be a small constant reduction of the risk in the air bag cars.

Table 2.1.4-3 shows the overall effectiveness estimates obtained for these collisions. It is noteworthy that the estimates of the reduction of total deaths in cars with air bags, and the averages of the risk reductions in the individual cases are the same. This is compatible with the pattern shown in Figure 2.1.4-13, that the air bag effect independent of the predicted risk for cars without air bags.

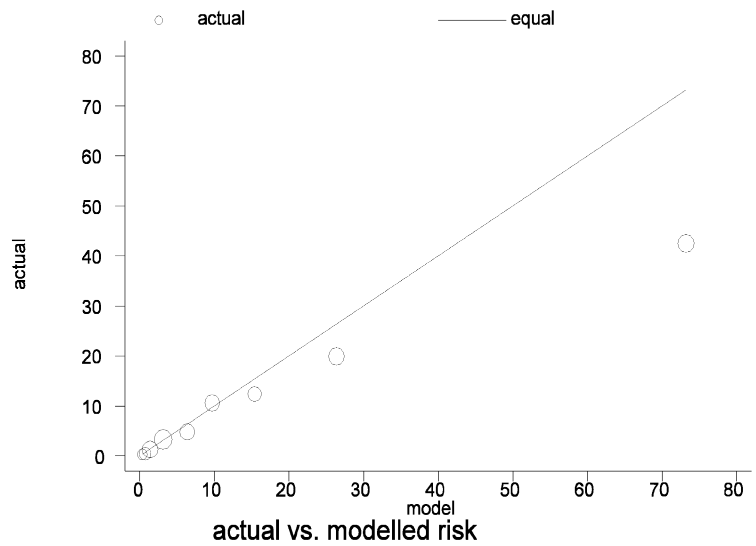


Figure 2.1.4-12 Actual driver fatality risk in cars with air bags versus modelled risk for cars without air bags. Cars struck on the left side by the front of another car.

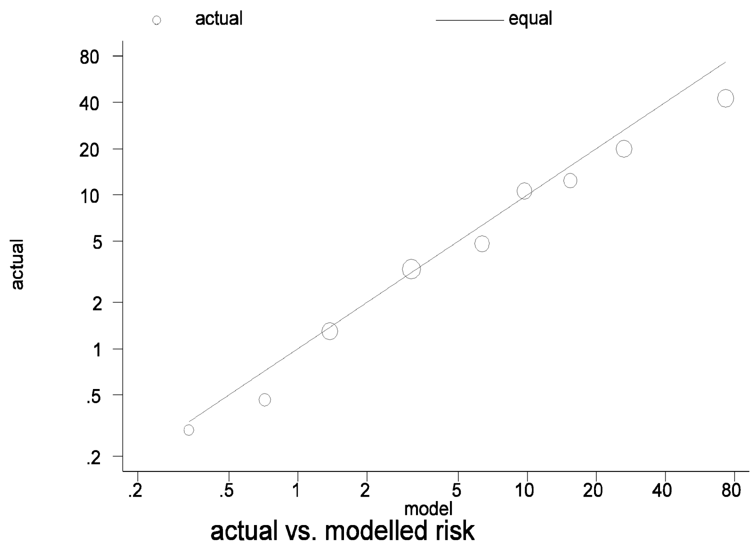


Figure 2.1.4-13 Actual driver fatality risk in cars with air bags versus modelled risk for cars without air bags. Cars struck on the left side by the front of another car. Double logarithmic scales.

Table 2.1.4-3 Air bag effect (percent reduction of driver fatality risk) in collisions where the point of another car strikes the left side of the study car. Non-standard errors are in parentheses.

estimate	cars with air bag	cars with driver only air bag
reduction of total deaths	19 (9)	13 (11)
average reduction of fatality risks	19 (9)	13 (11)

Figure 2.1.4-14 shows the actual risks for cars with air bags, and the modelled risks for cars without air bags versus vehicle weight. Figure 2.1.4-15 shows the ratio of the actual to the modelled risk. There is no clear pattern, but a suggestion of an increasing air bag effect with increasing car weight. A similar pattern appears for speed limits of 55 mph or higher (Figure 2.1.4-17), for younger drivers, (Figure 2.1.4-18) and for women (Figure 2.1.4-21) where it might also be a step function; there appears to be no trend. With regard to driver age, there may be an increasing trend of effectiveness for men, (Figure 2.1.4-22), but none for women, (Figure 2.1.4-23). With regard to speed limit, there appears to be a trend of increasing effectiveness for men (Figure 2.1.4-24), but non for women.

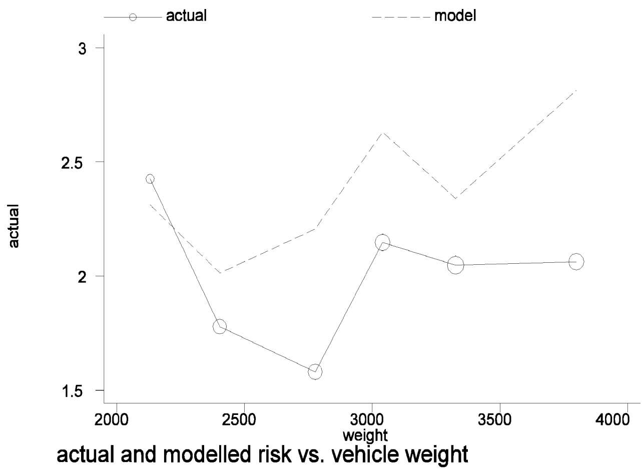


Figure 2.1.4-14 Actual driver fatality risk in cars with air bags, and risk predicted for cars without air bags versus car weight. Car struck on the left side by the front of another car.

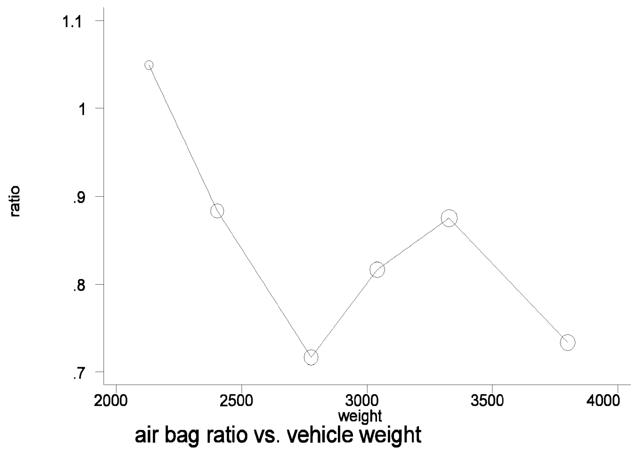


Figure 2.1.4-15 Ratio of the actual driver fatality risk in cars with air bags to the risk predicted for cars without air bags versus car weight. Car struck on the left side by the front of another car.

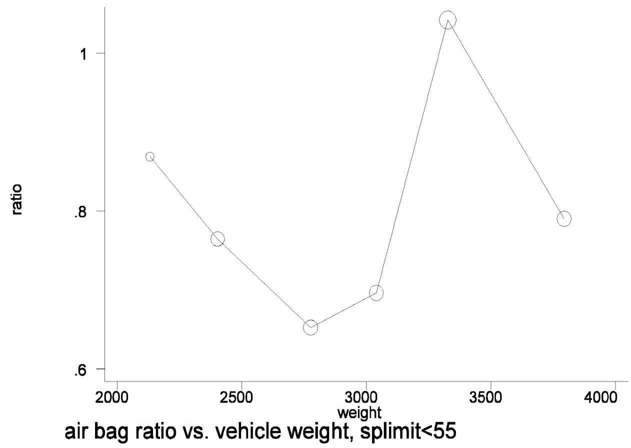


Figure 2.1.4-16 Ratio of the actual driver fatality risk in cars with air bags to the risk predicted for cars without air bags versus car weight. Speed limit < 55 mph. Car struck on the left side by the front of another car.

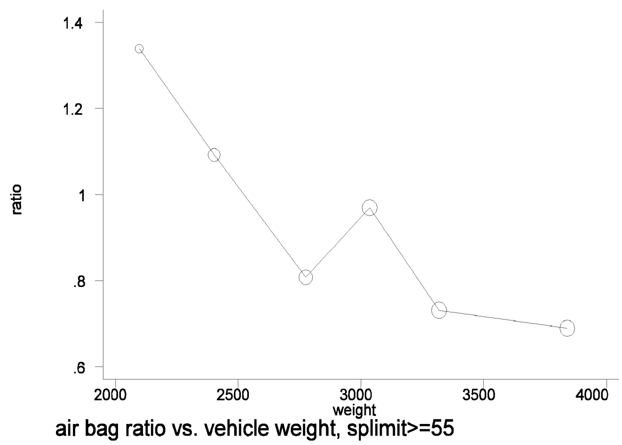


Figure 2.1.4-17 Ratio of the actual driver fatality risk in cars with air bags to the risk predicted for cars without air bags versus car weight. Speed limit > =55 mph. Car struck on the left side by the front of another car.

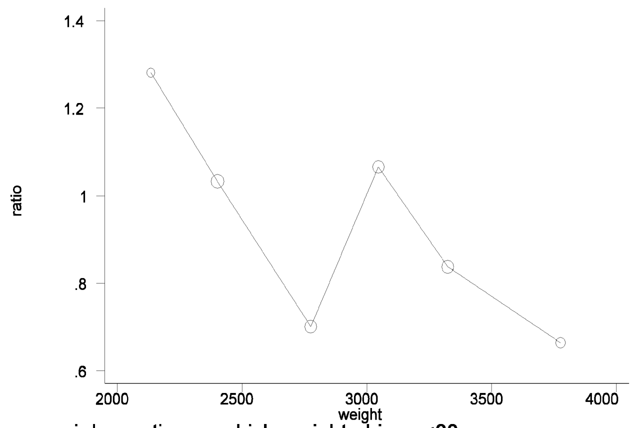


Figure 2.1.4-18 Ratio of the actual driver fatality risk in cars with air bags to the risk predicted for cars without air bags versus car weight. Driver age < 60 years. Car struck on the left side by the front of another car.

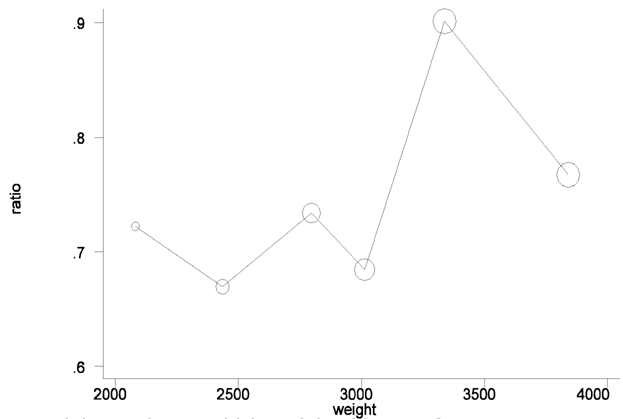


Figure 2.1.4-19 Ratio of the actual driver fatality risk in cars with air bags to the risk predicted for cars without air bags versus car weight. Driver age > =60 years. Car struck on the left side by the front of another car.

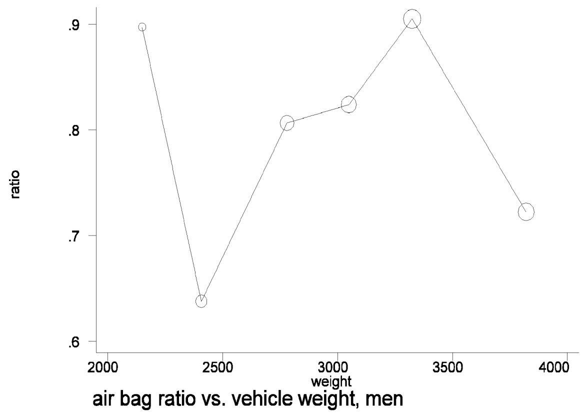


Figure 2.1.4-20 Ratio of the actual driver fatality risk in cars with air bags to the risk predicted for cars without air bags versus car weight. Male driver. Car struck on the left side by the front of another car.

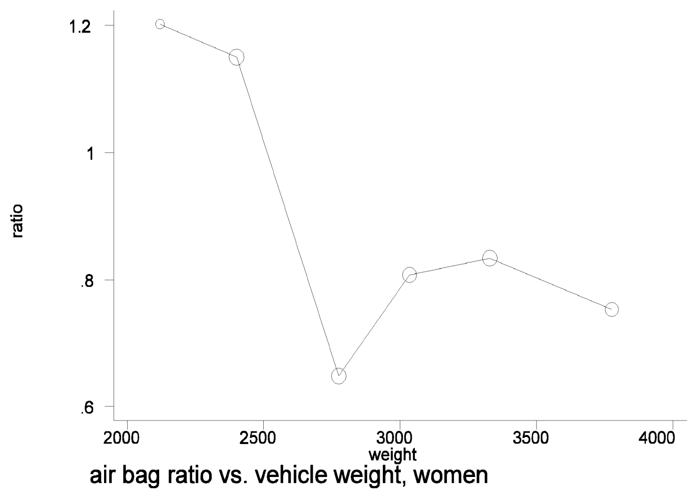


Figure 2.1.4-21 Ratio of the actual driver fatality risk in cars with air bags to the risk predicted for cars without air bags versus car weight. Female driver. Car struck on the left side by the front of another car.

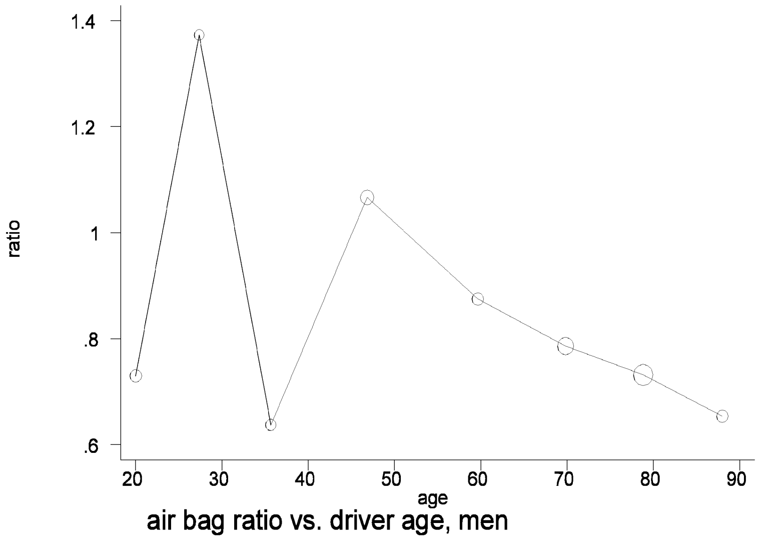


Figure 2.1.4-22 Ratio of the actual driver fatality risk in cars with air bags to the risk predicted for cars without air bags versus driver age. Male driver. Car struck on the left side by the front of another car.

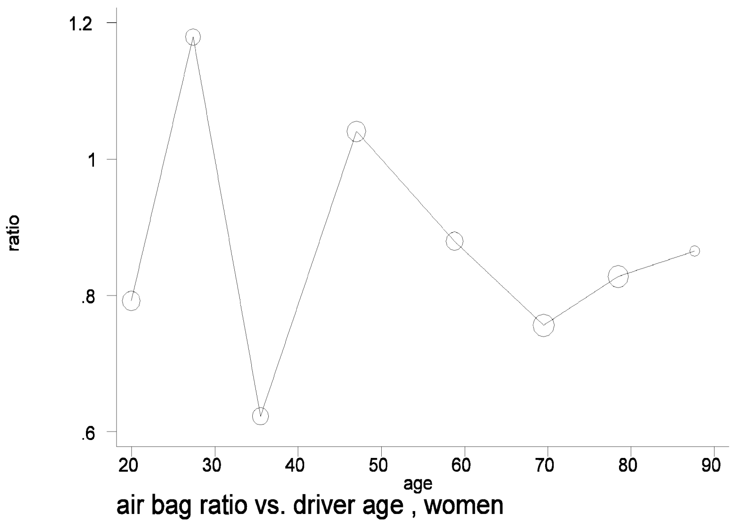


Figure 2.1.4-23 Ratio of the actual driver fatality risk in cars with air bags to the risk predicted for cars without air bags versus driver age. Female driver. Car struck on the left side by the front of another car.

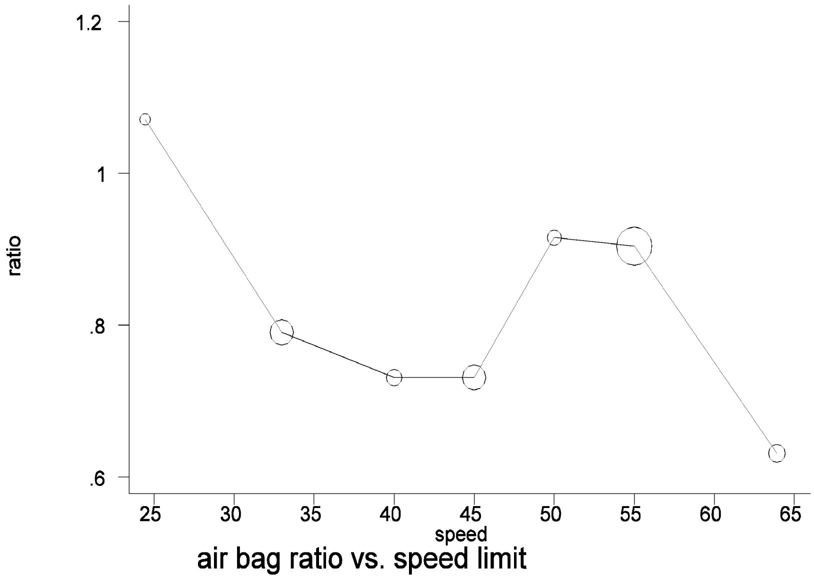


Figure 2.1.4-24 Ratio of the actual driver fatality risk in cars with air bags to the risk predicted for cars without air bags versus speed limit. Car struck on the left side by the front of another car.

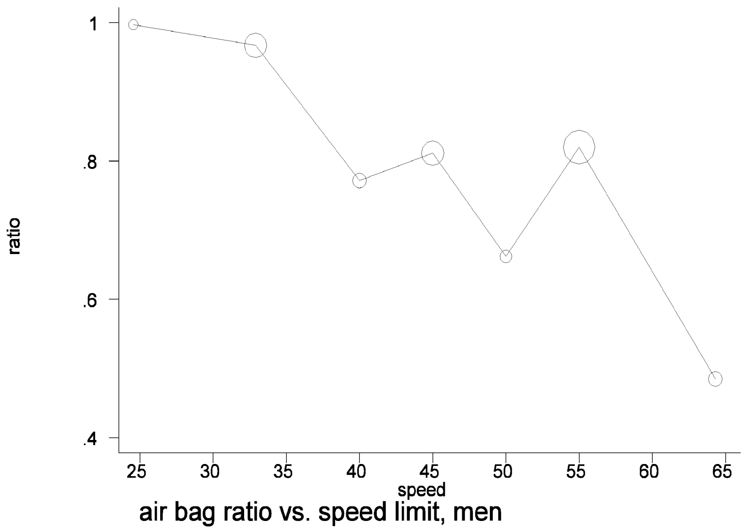


Figure 2.1.4-25 Ratio of the actual driver fatality risk in cars with air bags to the risk predicted for cars without air bags versus speed limit. Male driver. Car struck on the left side by the front of another car.

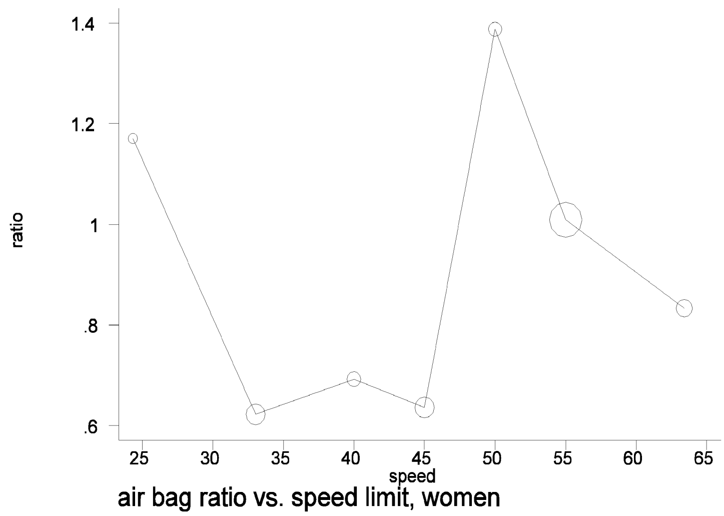


Figure 2.1.4-26 Ratio of the actual driver fatality risk in cars with air bags to the risk predicted for cars without air bags versus speed limit. Female driver. Car struck on the left side by the front of another car.

To identify possible interactions which might explain these complicated factors, the ratio of death to predicted risk was modelled by linear regression, using the factors used in all modelling, and also the interactions of any two of them. The results are shown in Table 2.1.4-4.

Table 2.1.4-4 Coefficients of models for air bag effect (proportional change in driver fatality risk) in cars struck on the left side by the front of another car. Non-standard errors in parentheses.

variable	model 1	model 2	model 3
female	-.26 (.13)		-.30 (.16)
female ∗ log(weight/2,800)		-1.27 (.51)	-1.21 (.51)
female ∗ (age -30)/10		.086 (.032)	.12 (.04)
constant	-.039 (.12)	-.20 (.10)	- .039 (.12)

If no interactions were allowed, driver sex was the only significant variable (Model 1). If interactions were allowed, only the interaction with weight appeared for female drivers, and the interaction with age for female drivers (Model 2). This is surprising, since Figure 2.1.4-17 suggests an effect of car weight for high speed limits and Figure 2.1.4-18 for younger drivers. Figure 2.1.4-22 suggests an age term for male drivers - but when forced into the model, it is well within the random variability. Figure 2.1.4-24 suggests an effect of the speed limit for men, but none appears in the model. All this is not completely surprising, since the points in the figures are confounded by all the other variables and do not show the pure effect of the independent variables against which they are plotted.

If one forces driver sex into model 2, one obtains model 3. The coefficient for female is practically the same as in Model 1, the car weight term for women is practically the same as in model 2, and only the age term for women, and the constant term are substantially changed.

To obtain a less detailed but possibly more robust picture, effectiveness estimates were made for low and high values of the variables studied. The results are shown in Table 2.1.4-5. Surprising is that a large risk reduction was found for high predicted risks, and only very little for low predicted risks, contrary to what one would expect from Figure 2.1.4-13. However, this is due to the choice of the division at a risk of 12/1,000. If 2/1,000 had been used, the difference would have been much smaller.

With one exception, the effectiveness seems to be greater for women than for men, and for lower speed limits it seems to be consistently greater than for higher ones -

agreeing with Figure 2.1.4-24, if one considers that there are only very few cases with speed limits under 30 mph, or over 60 mph. There is no clear pattern with regard to driver age nor car weight.

In sum, there seems to be a risk reduction even in left side impacts, but its magnitude is not very certain, and it's possible dependence on other factors is also uncertain.

Table 2.1.4-5 Driver fatality risk reduction (percent) in cars with air bags relative to the model for cars without air bags, in cars struck on the left side by the front of another car. Estimates E1 are for the reduction of total deaths, estimates E2 are for the average of the risk reductions in each case. Negative signs indicate a detrimental effect. Non-standard errors are in parentheses.

subset of cases	cars with air bags		cars with driver only air bags	
	E1	E2	E1	E2
risk < 12/1,000	9 (8)	18 (10)	5 (9)	11 (11)
risk > =12/1,000	31 (14)	28 (13)	23 (20)	26 (17)
men	20 (12)	3 (10)	-5 (17)	5 (16)
women	16 (10)	29 (10)	20 (12)	24 (12)
age <60	12 (9)	23 (10)	5 (11)	17 (12)
age >=60	23 (13)	-5 (16)	17 (15)	-11 (18)
car weight < = 2,800 lb	17 (14)	16 (14)	17 (13)	13 (16)
car weight > 2,800 lb	19 (10)	19 (10)	10 (12)	11 (14)
speed limit < 55 mph	21 (12)	19 (10)	14 (11)	13 (11)
speed limit > = 55 mph	16 (15)	6 (15)	10 (22)	-8 (23)

2.2 Single car crashes

Since air bags are not designed to deploy in rollovers, and are unlikely to have an effect during a rollover even if they deploy, only single car crashes where the first harmful event was not a rollover were studied. The vast majority of those are collisions with a fixed object. Table 2.2-1 shows the case numbers available for the analyses.

Table 2.2-1 Numbers of single car crashes used for modeling fatality risks and estimating air bag effectiveness in single car crashes.

impact	code		number	percent
	FARS	GES		
front	12	1	15041	53
right side	3	2	3034	11
left side	9	3	3762	13
other			6319	23
all			28156	100

2.2.1 Single car crashes with any impact

One can not expect to get a simple functional model for crashes with all impacts combined, because they include crashes with very different injury causation mechanisms, such as frontal impacts and side impacts, where different factors influence the fatality risk in different ways. Even if one gets a model which represents the data well, it does not necessarily reflect the physical effects of the various factors, because the combination of several relations can result in a very different overall relation. The effect which is behind the well-known “Simpson’s Paradox” can e.g., create a U-shaped relation when several linear relations with the same sign of the slope are combined. Therefore models which describe combinations of different crash configurations need to be interpreted with great caution.

Table 2.2.1-1 shows the number of cases available. The 18,470 cases where the car had no air bag were used to develop a fatality risk model, the coefficients of which are shown in Table 2.2.1-2. A few coefficients would not be considered significant by conventional standards, but they definitely improve the fit of the model for in some ranges of the variables. Also, some of the terms just represent those parts of nonlinear relations where the non-linearity becomes strong.

Table 2.2.1-1 Case numbers for single car crashes

cars with	FARS	GES
no air bag	10845	7625
air bag	4670	5016

Table 2.2.1-2 Model coefficients for the driver fatality risk in cars without air bags in single car crashes.

variable	coefficient	non-standard error
splimit = 55	.38	.19
splimit > 55	-.58	.23
log(weight/2300) ∗ (weight<2300)	-.88	.53
log(weight/3300) ∗ (weight>3300)	-1.61	.70
(age-60) ∗ (splimit -55)/1000	-.55	.12
female	-.67	.04
(age-30) ∗ (age<30)/10	.30	.05
(age-50) ∗ (age>50)/10	.39	.06
log (weight/2900) ∗ (weight <=2900) ∗ (splimit>55)	-3.67	1.51
log (weight/2800) ∗ (splimit =55)	.53	.25
(age-50) ∗ (age>50) ∗ (splimit >55)/10	.45	.15
log (weight/2300) ∗ (weight<=2300) ∗ (splimit=55)	-1 .54	.77
constant	-4.21	.15

Figure 2.2.1-1 shows the overall very good agreement between the modelled and the actual risks. Since such a gross comparison could hide systematic differences between the model and the actual risks, 24 graphs comparing the actual and modelled risks in relation to the model variables were examined. In general, the agreement was good. A few examples are shown.

Figure 2.2.1-2 shows actual and modelled fatality risks versus car weight. Note that this and the following Figures include the effects of confounding factors. With the exception of the highest weights, the agreement is very good. Aggregating the cases with the highest weights into one point would have shown even better agreement.

Figures 2.2.1-3 and 4 show an interesting interaction between car weight and driver age. For the older drivers, the fatality risk declines with car weight. For the younger drivers, the relation is complex: in the middle range when the case numbers are largest, there appears to be an increase of the risk with car weight, but opposite trends for the lowest and the highest weights. What is important is that the model represents such different apparent relations well.

Figures 2.2.1-5 and 6 show the relations between risk and driver age, separately for men and women. Overall, risks and model agree well, though for men the risks appear to increase faster than the model predicts above 70 years, and for women above 60 years. However, the model could not be "tweaked" to represent this perfectly.

Figure 2.2.1-7, shows the actual and modelled risks versus the speed limit.

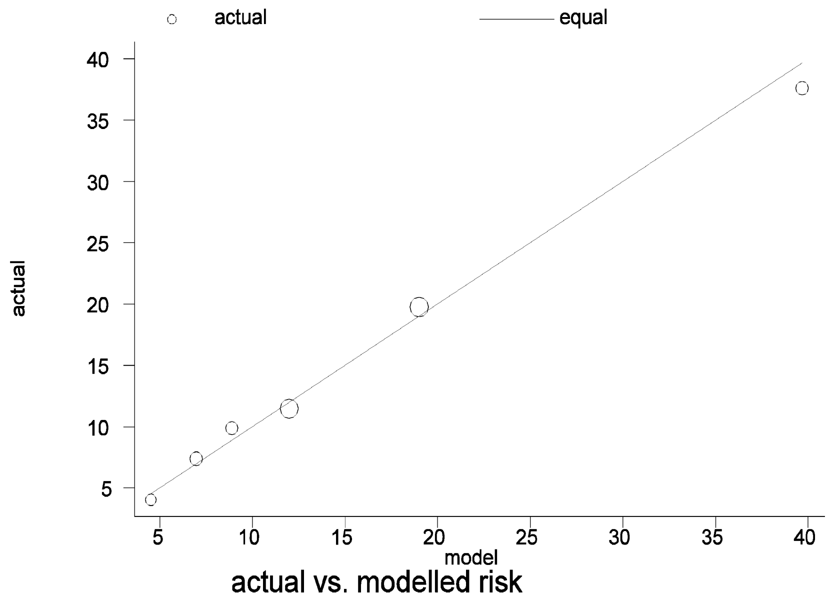


Figure 2.2.1-1 Actual versus modelled driver fatality risk (per 1000 involvements) in single car crashes, cars with no air bags.

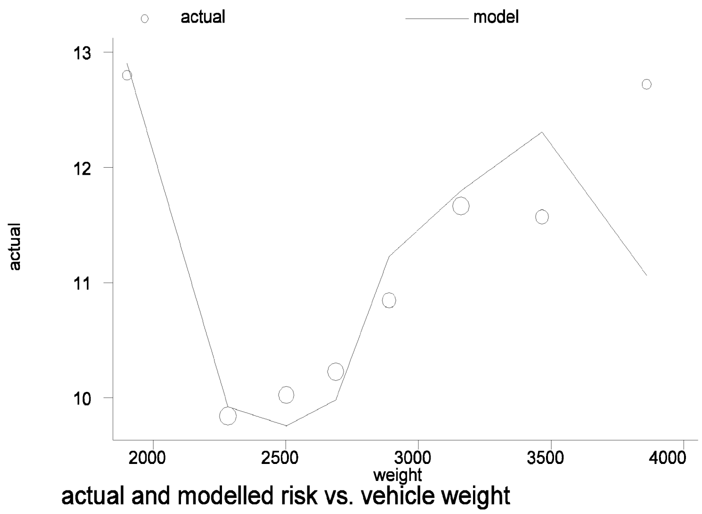


Figure 2.2.1-2 Actual and modelled driver fatality risk (per 1,000 involvements) in single car crashes versus vehicle weight. Cars with no air bags.

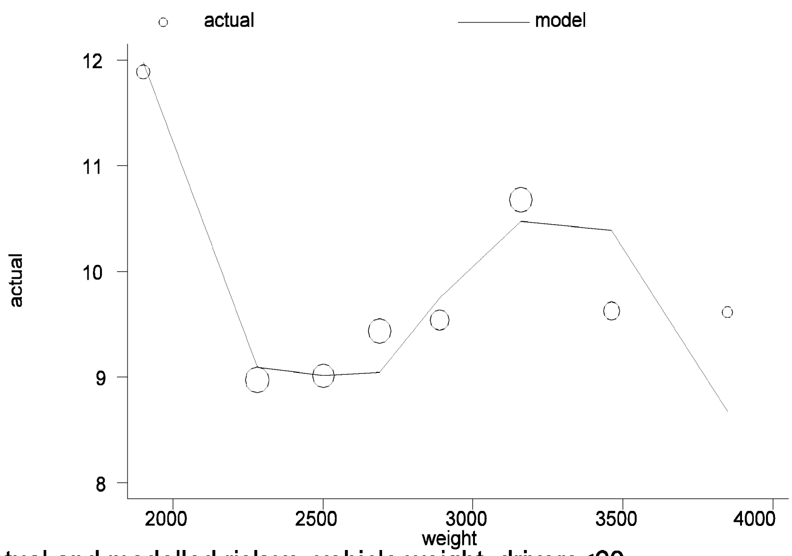


Figure 2.2.1-3 Actual and modelled driver fatality risk (per 1,000 involvements) in single car crashes, versus car weight. Driver less than 60 years old in car with no air bag.

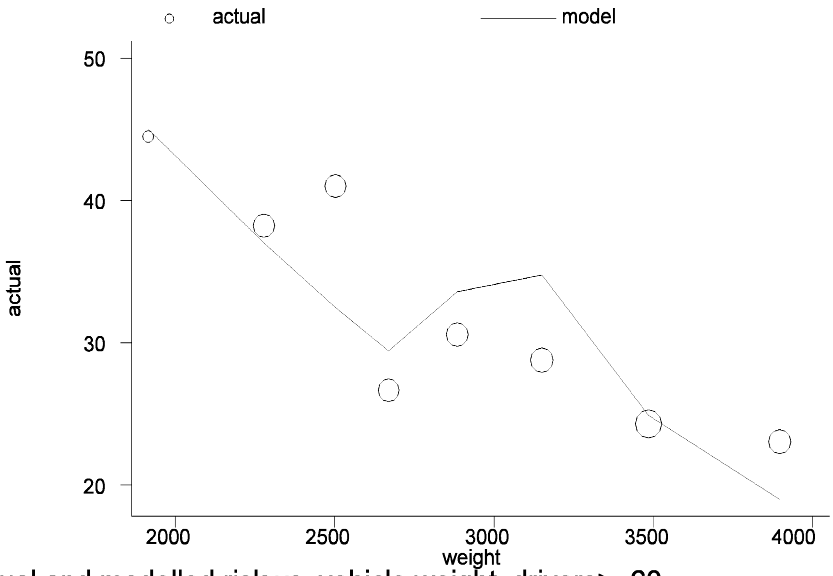
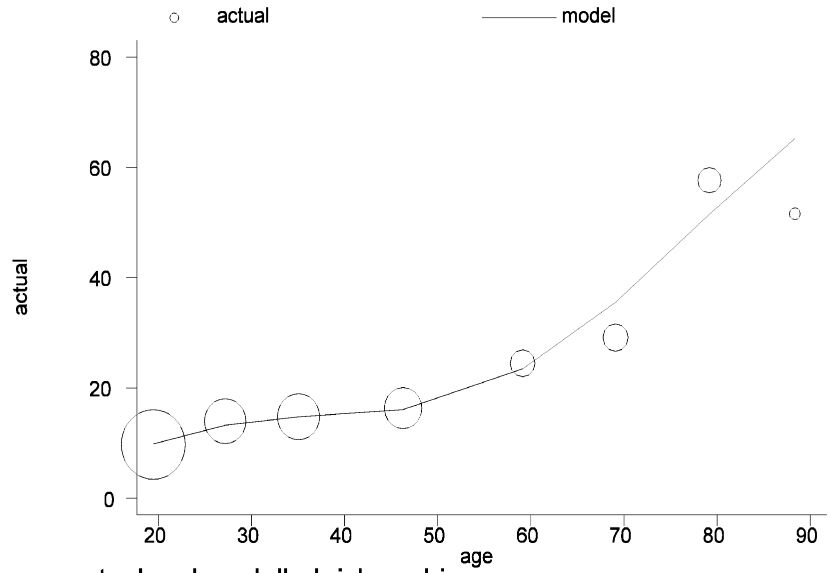
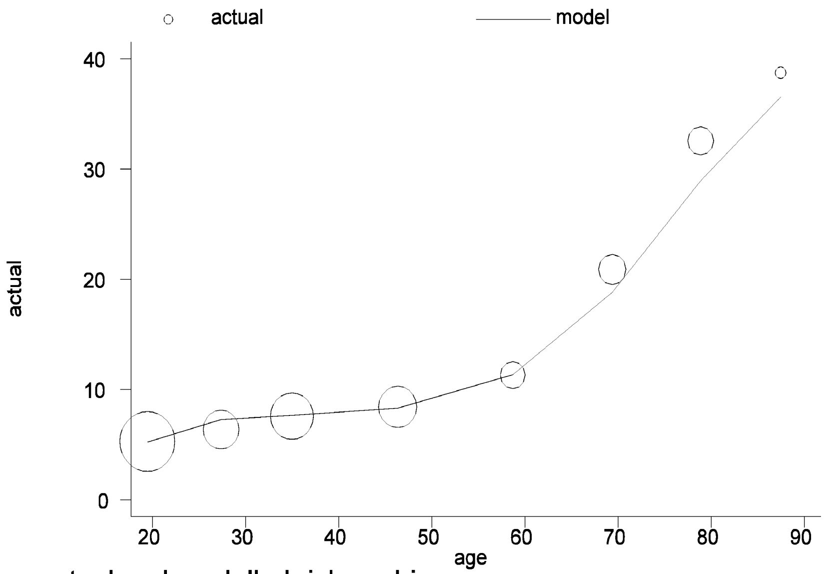


Figure 2.2.1-4 Actual and modelled driver fatality risk (per 1,000 involvements) in single car crashes. Driver 60 or over in car with no air bag.



actual and modelled risk vs.driver age, men

Figure 2.2.1-5 Actual and modelled driver fatality risk (per 1,000 involvements) in single car crashes versus driver age. Male drivers in cars with no air bag.



actual and modelled risk vs.driver age, women

Figure 2.2.1-6 Actual and modelled driver fatality risks (per 1000 involvements) in single car crashes versus driver age. Male driver in car with no air bags.

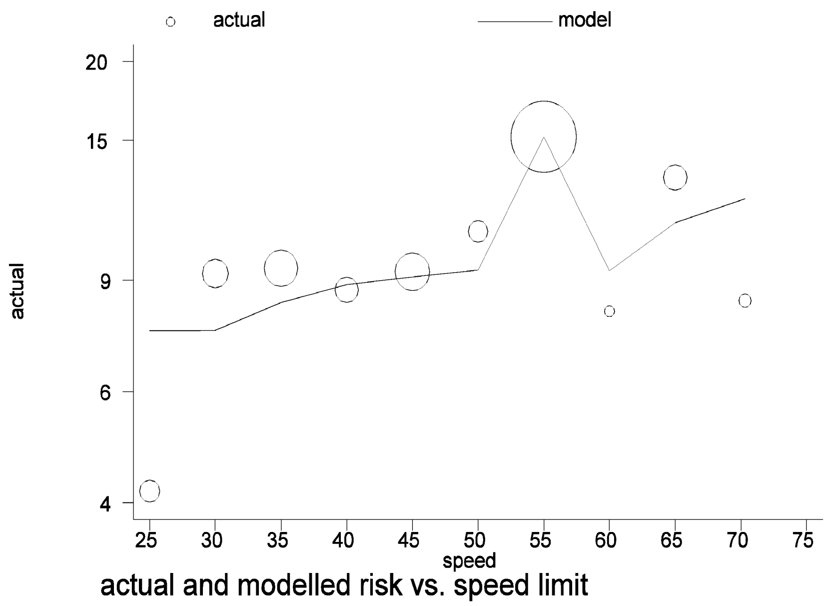


Figure 2.2.1-7 Actual and modelled driver fatality risk (per 1000 involvements) in single car crashes versus speed limit. Cars with no air bags. Logarithmic scale for the risk.

To estimate the effects of air bags, controlling for the confounding factors found relevant in the model for cars without air bags, the model was used to predict the fatality risk for the cases where the cars had an air bag and compare the actual and predicted values. In one approach, total driver deaths in the air bag cases were divided by the sum of the probabilities predicted for these cases. Another approach calculated for each air bag case

(actual - predicted)/predicted,

where actual equals either 1, for a FARS case, or 0 for a GES case. Then, the average of these ratios were calculated, using the GES expansion factors, and a factor of 1 for the FARS cases.

The results are shown in Table 2.2.1-3. Both approaches give practically the same value, and there is also no difference between cases with driver-only air bags, or with dual air bags.

Table 2.2.1-3 Driver fatality risk reduction in cars with air bag relative to the model for cars with no air bag. Non-standard errors in parentheses.

estimated as	all cars with air bag	cars with driver only air bag
reduction of total deaths	33 (8)	32 (7)
average reduction of fatality risks	32 (8)	32 (8)

A more detailed picture is shown in Figures 2.2.1-8 and 9. The actual risk in air bag cases is shown versus that predicted by the model for non-air bag cases. Figure 2.2.1-8 shows that the absolute reduction increases with risk, and with the double logarithmic scale of Figure 2.2.1-9 one sees that the relative reduction is approximately constant.

Figure 2.2.1-10 shows actual and predicted risks versus car weight, and Figure 2.2.1-11 the ratio of the two. It indicates a risk reduction of slightly more than 30%, essentially independent of weight.

Figures 2.2.1-12 to 17 shows actual and predicted risks versus vehicle weight for different subsets of the data base. No clear patterns appear.

Figures 2.2.1-18 and 19 show the ratios of the actual to the predicted risks, versus driver age separately for men and women. In both cases, there seem to be much stronger trends than in the plots versus weight. However, the signs of the slopes are opposite, and that for women is much less steep than for men.

Figure 2.2.1-20 shows the ratio of actual versus predicted risks versus speed limit. If one ignores the point for the lowest speeds, one sees an air bag effect increasing with high speed limit, but with that point there is no clear trend. A finer breakdown of the data shows no clear pattern either.

To explore this further, regression analyses were performed with the ratios (actual - predicted)/predicted as dependent variable, using the survey regression technique. The coefficient of the resulting model are shown in Table 2.2.1-4. The constant coefficient means that for male drivers 30 years old, the air bag effect is a 23% reduction of the risk. For a 20 year old man, the reduction is only 18%, for a 50 year old man 32%, and for a woman, independent of age 41%. However, more complex relation between the effect of air bags and the various factors influencing the risk can not be excluded.

Table 2.2.1-4 Coefficients of model for air bag effect in single car crashes.

variable	coefficient	non-standard error
female	-.18	.05
(age-30) * male/10	-.047	.016
constant	-.23	.08

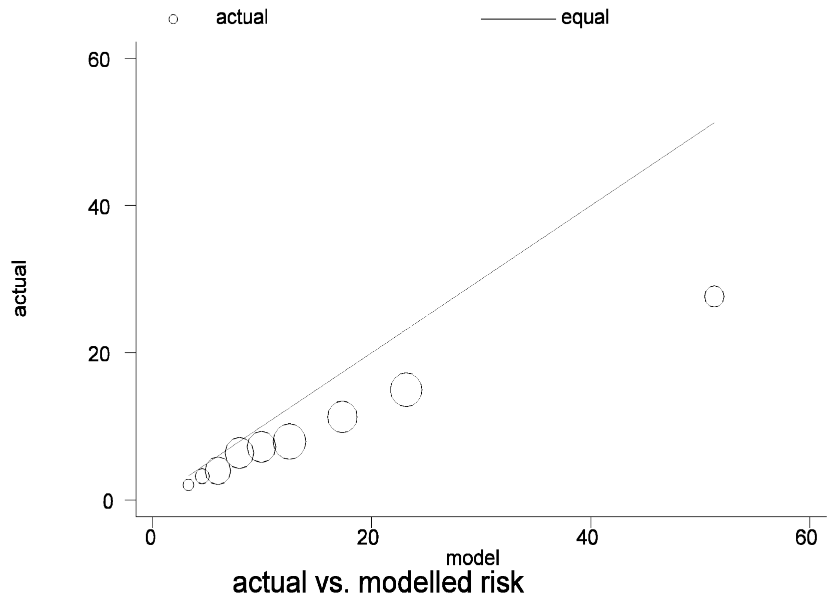


Figure 2.2.1-8 Actual driver fatality risk in air bag cars versus that predicted from the model for non-air bag cars.

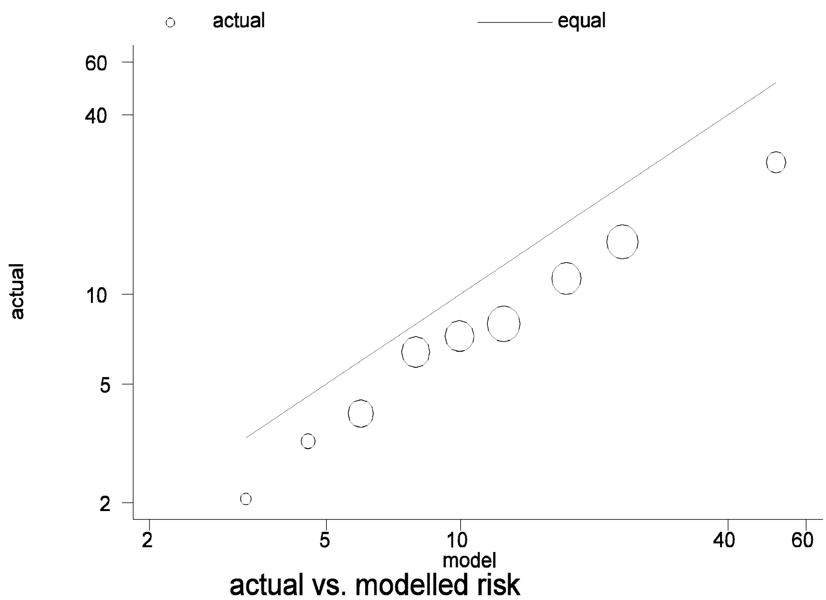


Figure 2.2.1-9 Actual driver fatality risk in air bag cases versus that predicted from the model for non-air bag case. Double-logarithmic scale.

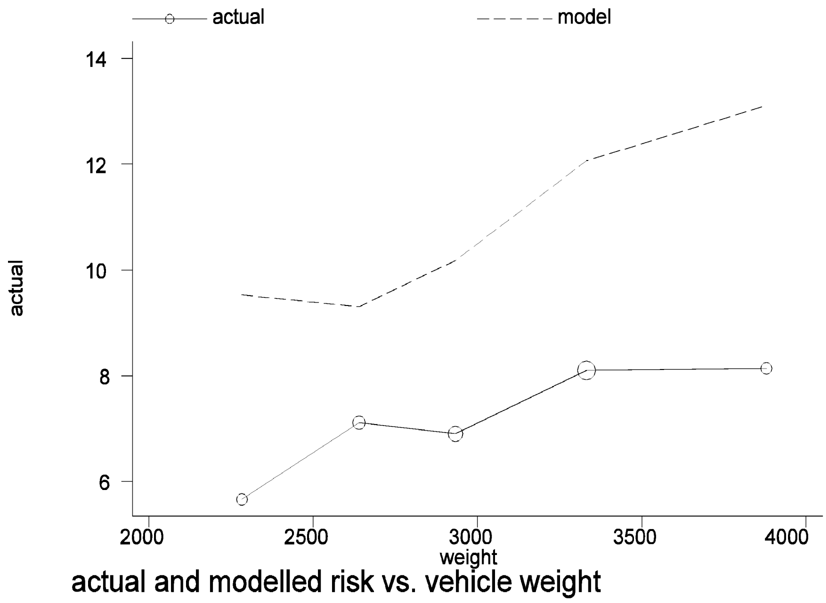


Figure 2.2.1-10 Actual driver fatality risk in cars with air bags, and the corresponding risk predicted from the model for non-air bag cases versus vehicle weight.

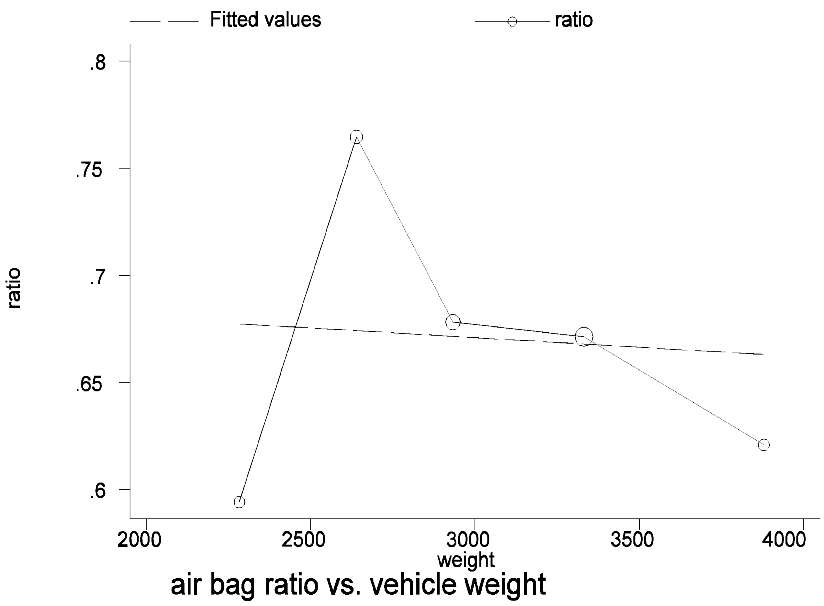


Figure 2.2.1-11 Ratio of the actual risk in air bag cars to that predicted for cars without air bags versus vehicle weight in single car crashes.

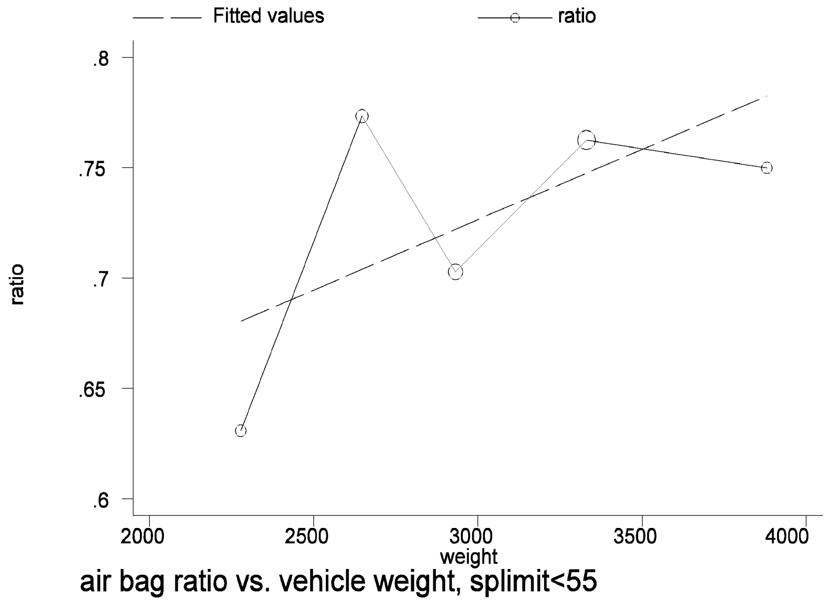


Figure 2.2.1-12 Ratio of the actual risk in air bag cars to that predicted for cars without air bags versus vehicle weight in single car crashes. Speed limit < 55 mph.

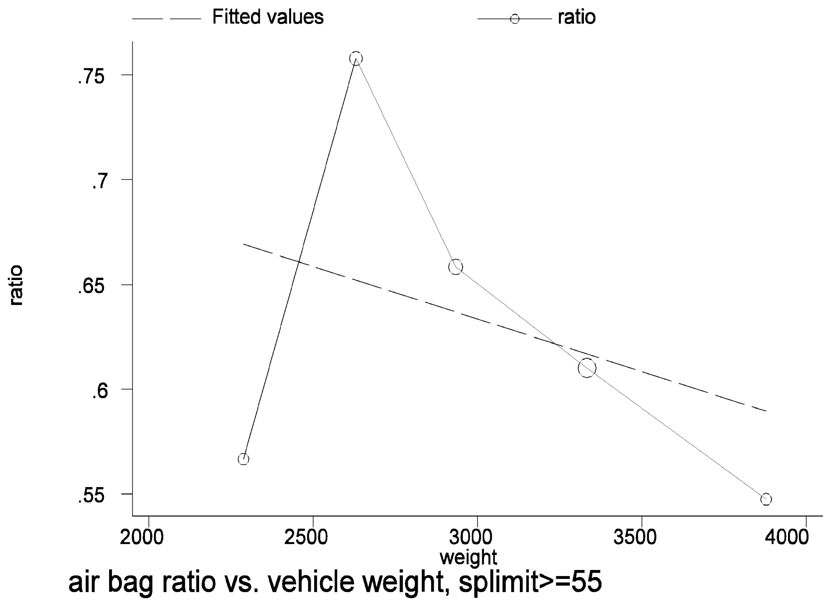


Figure 2.2.1-13 Ratio of the actual risk in air bag cars to that predicted for cars without air bags versus vehicle weight in single car crashes. Speed limit >= 55 mph

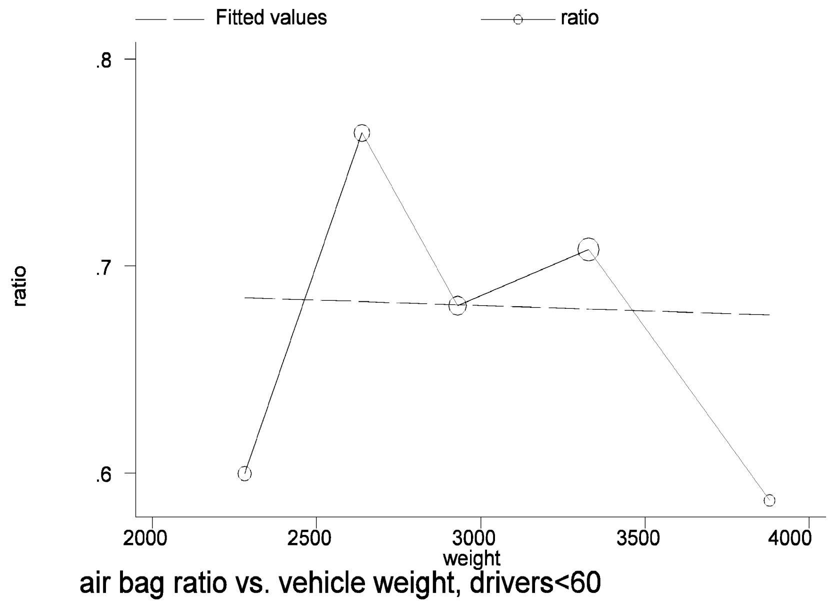


Figure 2.2.1-14 Ratio of the actual risk in air bag cars to that predicted for cars without air bags versus vehicle weight in single car crashes. Driver younger than 60 years.

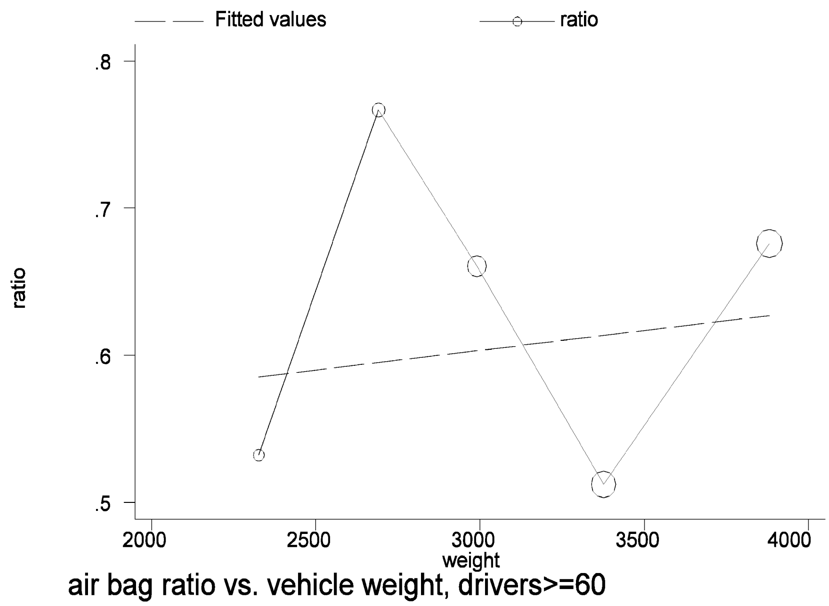


Figure 2.2.1-15 Ratio of the actual risk in air bag cars to that predicted for cars without air bags versus vehicle weight in single car crashes. Driver 60 years or older.

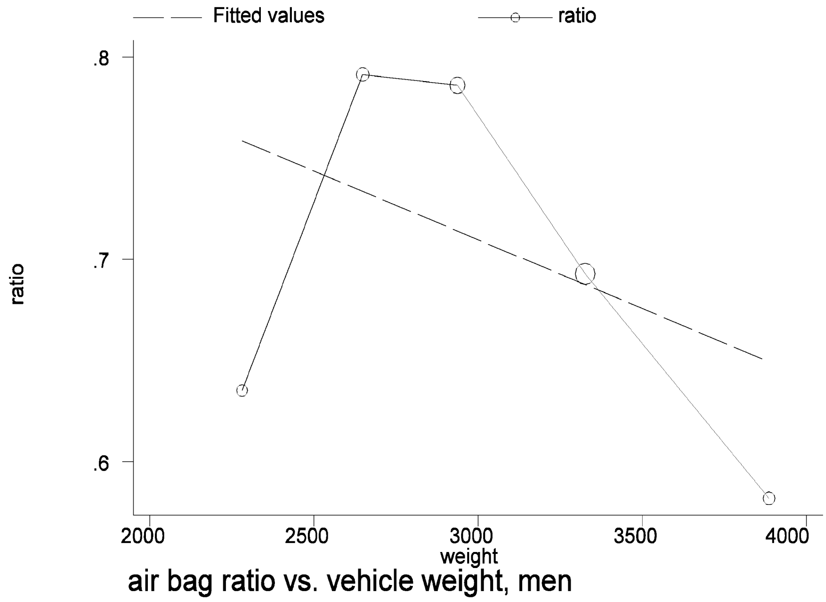


Figure 2.2.1-16 Ratio of the actual risk in air bag cars to that predicted for cars without air bags versus vehicle weight in single car crashes. Male drivers.

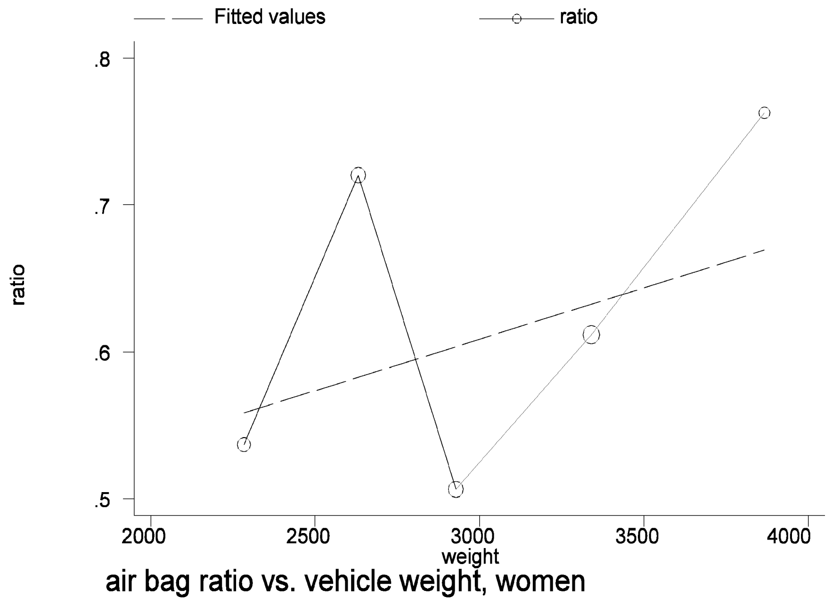


Figure 2.2.1-17 Ratio of the actual risk in air bag cars to that predicted for cars without air bags versus vehicle weight in single car crashes. Female drivers.

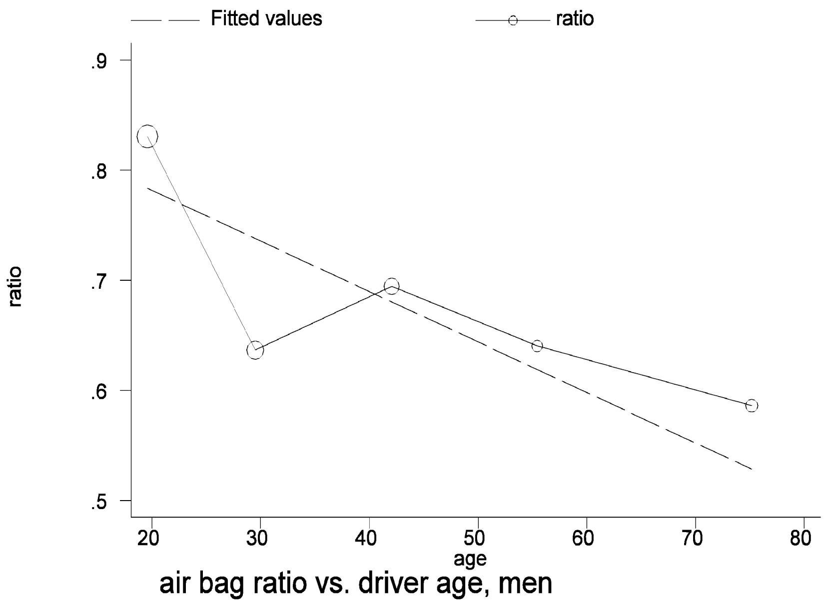


Figure 2.2.1-18 Ratio of the actual risk in air bag cars to that predicted for cars without air bags versus driver age in single car crashes. Male driver.

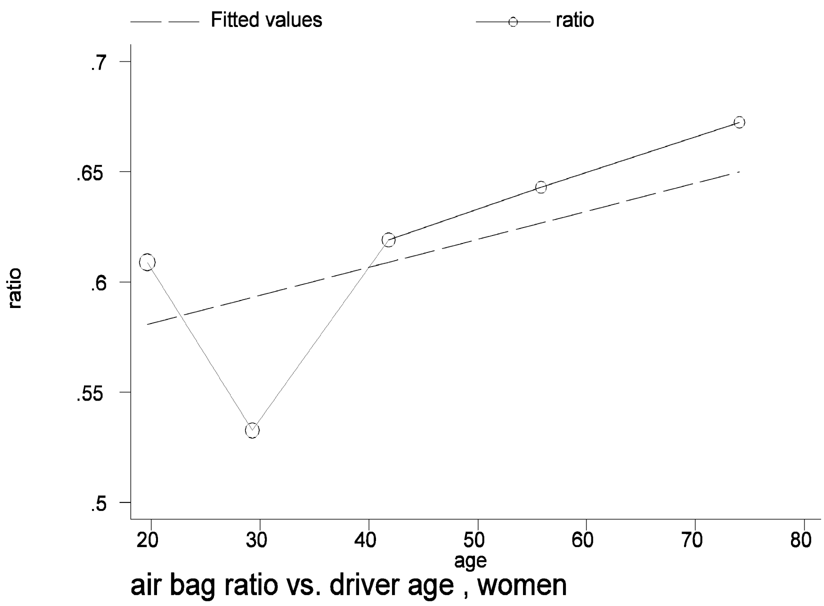


Figure 2.2.1-19 Ratio of the actual risk in air bag cars to that predicted for cars without air bags versus driver age in single car crashes. Female drivers.

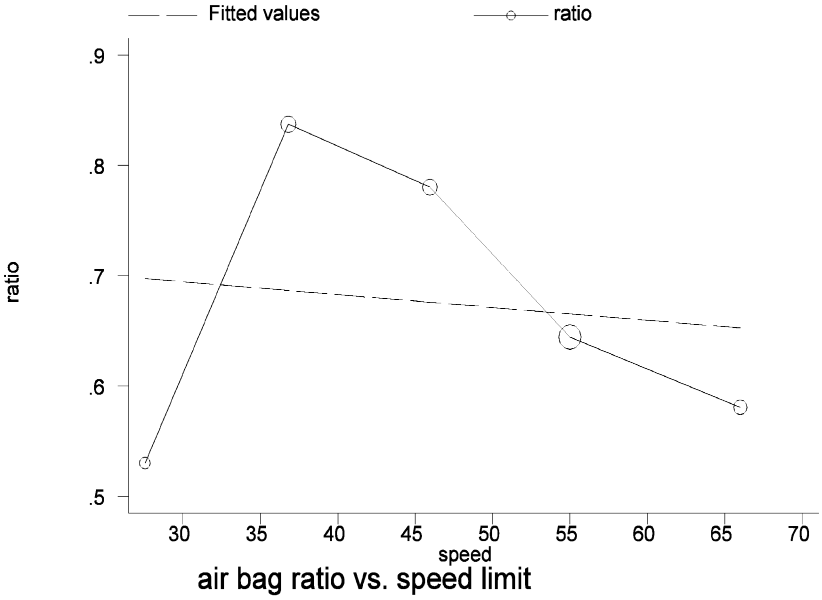


Figure 2.2.1-20 Ratio of the actual risk in air bag cars to that predicted for cars without air bags speed limit in single car crashes.

2.2.2 Frontal impacts in single car crashes

Air bags are designed to protect vehicle occupants in frontal impacts. Therefore, one expects them to have the greatest effect in frontal impacts. FARS cases with initial impact code 12, GES cases with initial impact code 1 were used. Table 2.2.2-1 shows the numbers of such cases, excluding cars with model years before 1985, and cases with variables needed for modeling missing. The total is a little more than half of the number of eligible cases. The numbers in the table can be used for a very crude estimate of air bag effectiveness: the cross product ratio of the numbers is 0.56, which correspond to a risk reduction by 44%. This argument ignores that GES cases have widely varying expansion factors, and that confounding factors may be correlated with the presence of an air bag. However, the estimate agrees well with the final estimates in Table 2.2.2-3

Table 2.2.2-1 Case numbers of single car crashes with frontal impacts.

cars with	FARS	GES
no air bag	5933	4318
air bag	2088	2702

Table 2.2.2-2 shows the coefficients of the model for driver fatality risk in cars with no air bags. It is the result of extensive analyses, including trial-and-error, to find suitable variables to reflect non-linear relations and interactions. Note that vehicle weight enters only in an interaction with driver age: for drivers over 30, the risk declines with vehicle weight, and the older the driver, the stronger the decline. For drivers under 30, the risk seems to increase with vehicle weight. A speculative explanation is that young drivers in heavier cars drive differently from drivers in lighter cars.

Figure 2.2.2-1 shows the good overall agreement between actual and modelled risks. Figure 2.2.2-2 shows the actual and the modelled risks versus car weight: the complicated trend is well represented, though there are, apparently random, deviations. The apparent increase of the risk with vehicle weight is due to the confounding effects of driver age and sex, heavier cars being driven by older drivers, and more likely by men than by women. This is supported by Figures 2.2.2-3 and 4. For drivers 60 and over, there is a clear decline of the risk with vehicle weight, as reflected in the age∗weight interaction term in Table 2.2.2-2. For younger drivers, Figure 2.2.2-3, the relation is essentially flat, with the exception of the point representing the weight range from 3,000 to 3,300 lb. Several “sporty” car models are in this weight range.

Figures 2.2.2-5 through 8 show that the model represents the data adequately with respect to car weight, within large, apparently random, variations. The only exceptions are the points representing cars over 3,700 lb in Figures 2.2.2-5 and 6, but they are based on very few cases.

The overall relations between risk and driver age is very well represented, Figure 2.2.2-9. Corresponding figures disaggregated by car weight, speed limit, and driver sex show also good, but not quite as good fit. They are not shown.

The overall relation between risk and speed limit is also well represented by the model, Figure 2.2.2-10. The corresponding figures for cases disaggregated by driver age and sex, and vehicle weight are similar. They are not shown.

Table 2.2.2-2 Model coefficients for the driver fatality risk in single car crashes with frontal impacts. Cars with no air bags.

variable	coefficient	non-standard error
splimit = 55	.47	.18
(age -60) ∗ (splimit -55)/1000	-.41	.14
(age -30) ∗ log (weight/2800)/10	-.32	.08
female	-.67	.04
(age-30) ∗ (age<30)/10	.31	.05
(age -50) ∗ (age>50)/10	.42	.07
(age -50) ∗ (age >50) ∗ (splimit >60)/10	.33	.15
constant	-4.29	.14

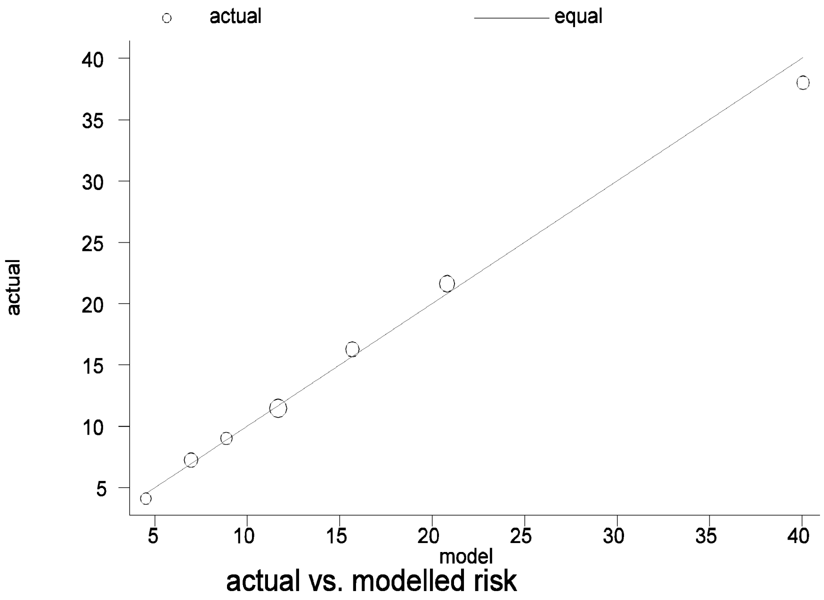


Figure 2.2.2-1 Actual versus modelled driver fatality risk in single car crashes with frontal impact. Car with no air bag.

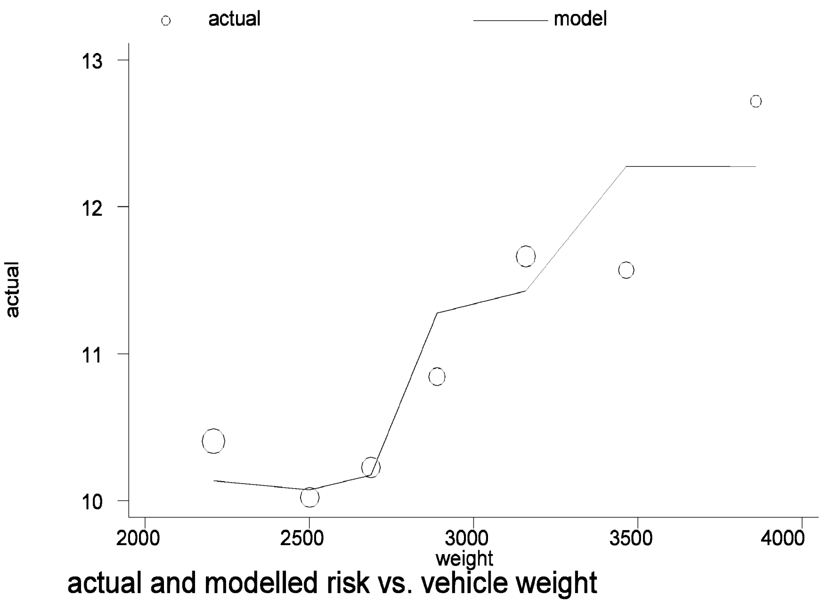


Figure 2.2.2-2 Actual and modelled driver fatality risk versus car weight. Single car crashes with frontal impact. Cars with no air bag.

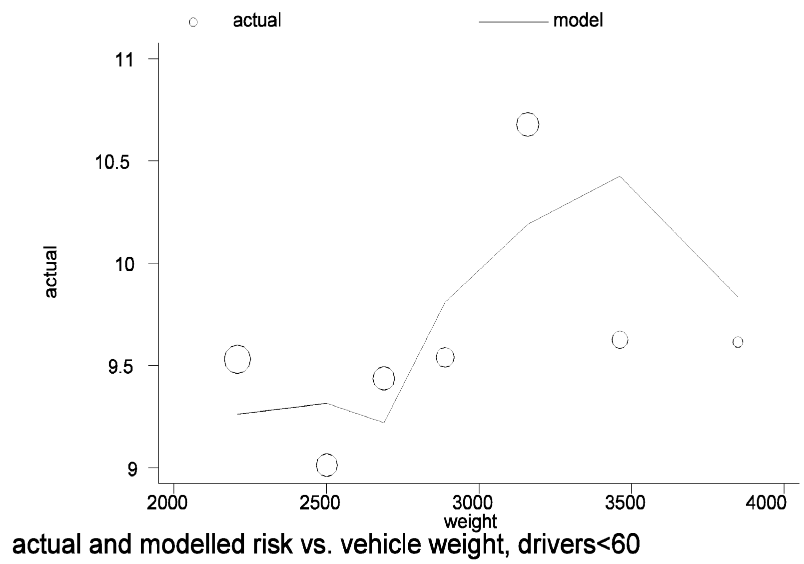


Figure 2.2.2-3 Actual and modelled driver fatality risk versus car weight in single car crashes with frontal impact. Driver under 60 years old. Car with no air bag.

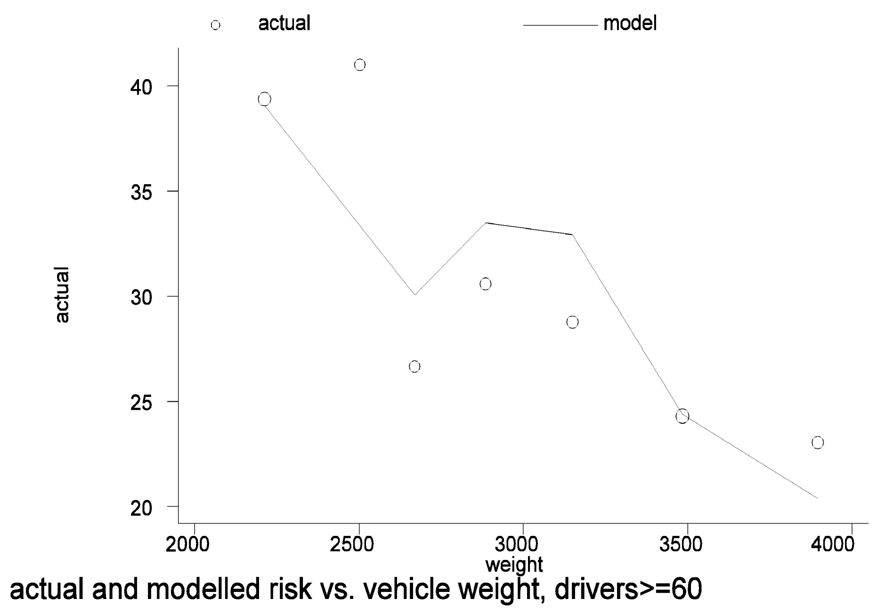


Figure 2.2.2-4 Actual and modelled driver fatality risk versus car weight in single car crashes with frontal impact. Driver 60 years or older. Car with no air bag.

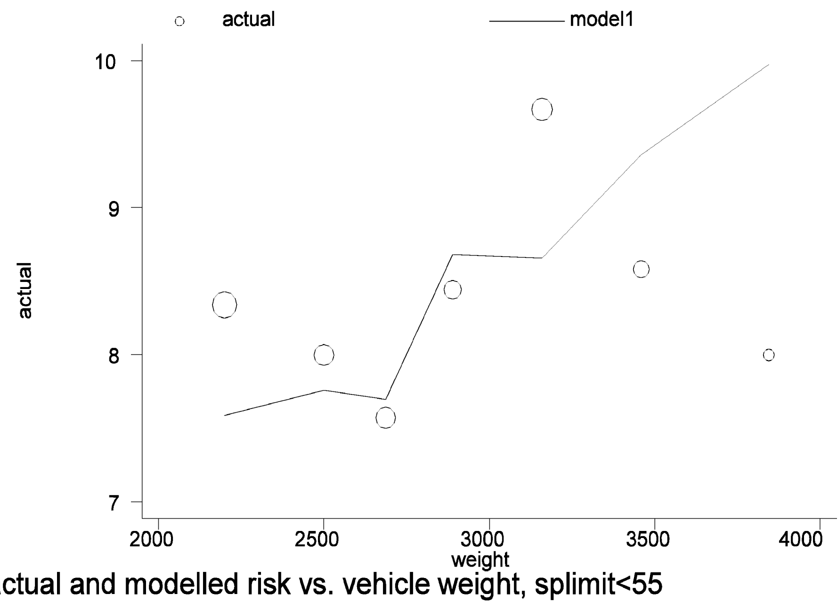


Figure 2.2.2-5 Actual and modelled driver fatality risk versus car weight, in single car crashes with frontal impact. Speed limit under 55 mph. Car with no air bag.

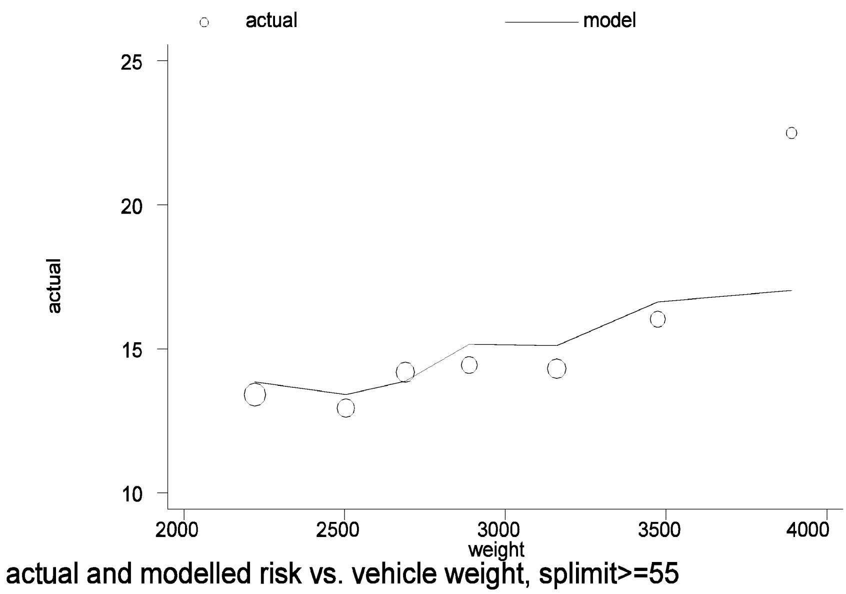


Figure 2.2.2-6 Actual and modelled driver fatality risk versus car weight in single car crashes with frontal impact. Car with no air bag. Speed limit 55 mph or higher.

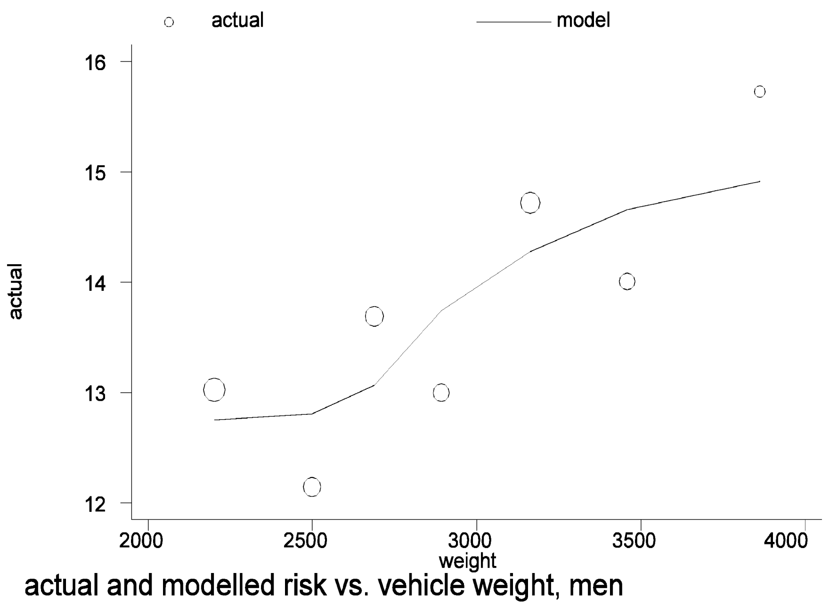


Figure 2.2.2-7 Actual and modelled driver fatality risk versus car weight in single car crashes with frontal impact. Car with no air bag. Speed limit 55 mph or higher. Male driver.

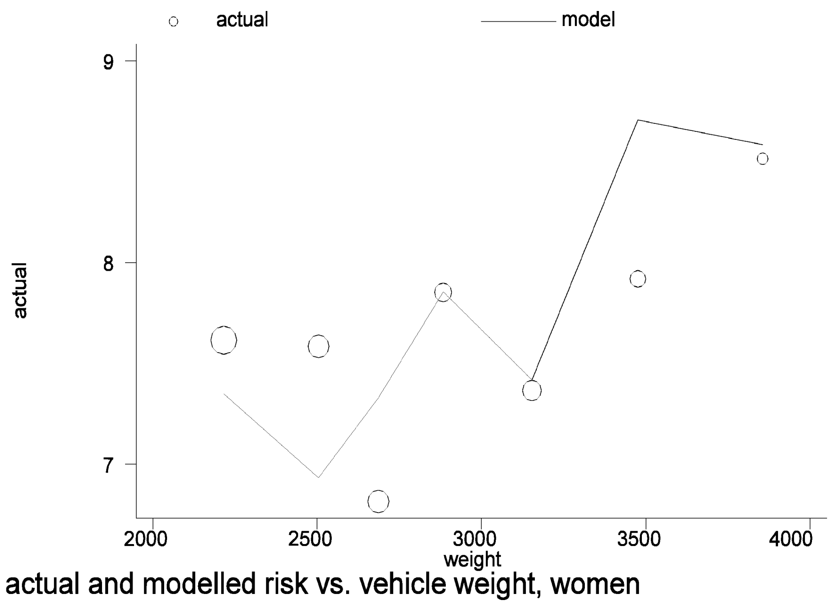


Figure 2.2.2-8 Actual and modelled driver fatality risk versus car weight in single car crashes with frontal impact. Car with no air bag. Speed limit 55 mph or higher. Female drivers.

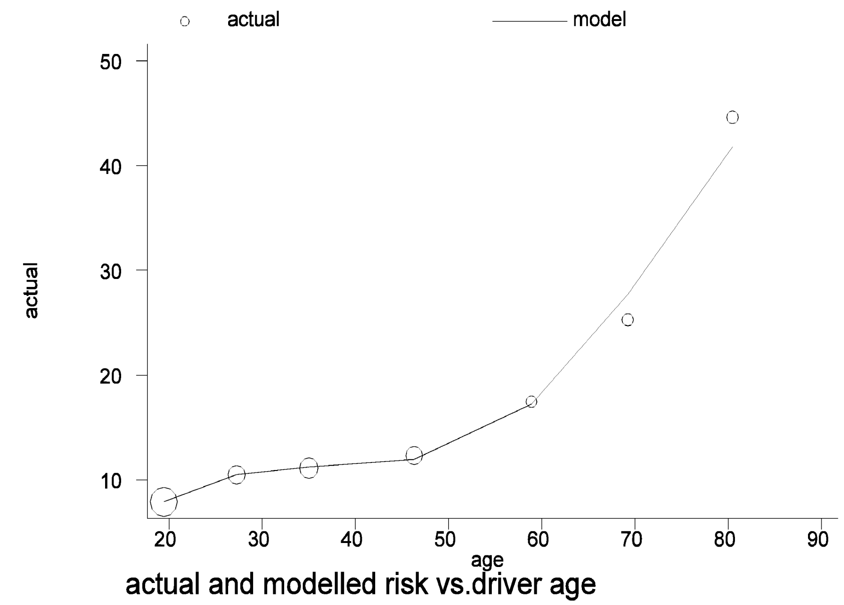


Figure 2.2.2-9 Actual and modelled driver fatality risk versus driver age. Single car crashes with frontal impacts, car with no air bags.

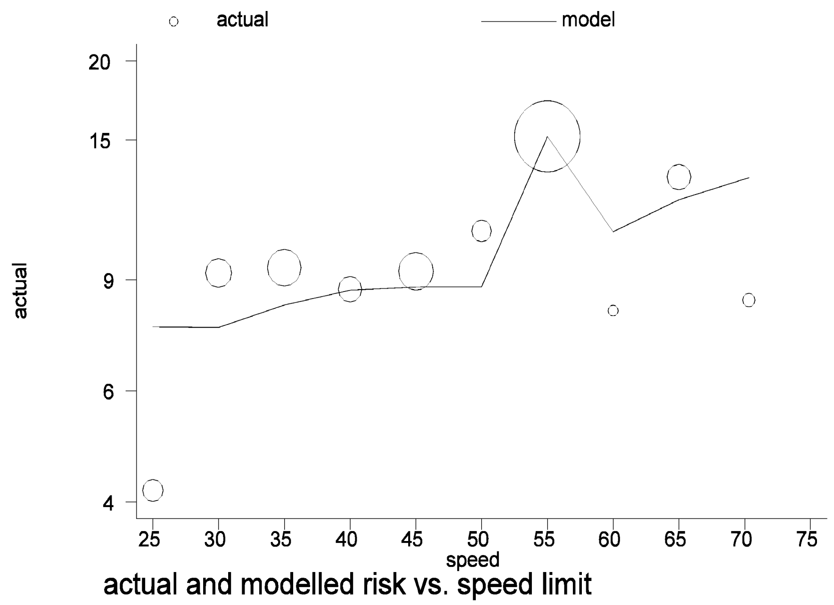


Figure 2.2.2-10 Actual and modelled driver fatality risk versus speed limit. Single car crashes with frontal impact, car without air bags.

Figures 2.2.2-11 and 12 show the actual driver fatality risks in cars with air bags, versus those predicted for these crashes from the model for cars without air bags. In Figure 2.2.2-12, with the double-logarithmic scale, the circles fall closely around a line parallel to the line indicating equality. That shows that the percentage risk reduction by air bags in frontal impacts in single vehicle crashes is constant for all levels of risk. Table 2.2.2-3 shows the reduction to be slightly over 40%. That is surprisingly close to the very rough estimate of 44% based on the case numbers in Table 2.2.2-1 without any control for confounding factors.

Table 2.2.2-3 Driver fatality risk reduction (percent) in cars with air bag relative to the model for cars with no air bag. Single car crashes with frontal impact. Non-standard errors in parentheses.

estimated as	cars with air bag	cars with driver only air bag
reduction of total deaths	43 (8)	42 (7)
average reduction of fatality risks	42 (6)	39 (7)

To determine whether and how the effect of air bags depends on crash factors, the relative reductions for each case, (actual-expected)/expected, were regressed on the variables. Table 2.2.2-4 shows the result as “model 1". These coefficients mean that for a woman, independent of her age, the risk reduction by an air bag is 50%(=16+34) For men 30 years old it is only 34%, for men 20 years old 30%, for men 40 years old it is 36% for men 50 years old it is 42%, and for men 60 years old it would be 46%, if one is willing to assume that this simple linear model still holds for the higher ages.

Figures 2.2.2-13 through 19 show the risk reduction vs. vehicle weight. If one considers only monotone increasing, flat, or decreasing trends, the risk reduction appears to be independent of car weight. However, all figures show a constant pattern that the risk reduction is lowest for cars between 2,500 and 3,000 lb weight, and highest for the lightest and the heaviest cars (with one exception: for female drivers). Therefore, a “broken” relation between risk reduction and weight was allowed for model 2.

Table 2.2.2-4 Coefficient of models for air bag effects in single car crashes, frontal impacts.

	Model 1		Model 2	
variable	**coefficient**	**non-standard error**	**coefficient**	**non-standard error**
female	**-.16**	**.04**	**-.12**	**.05**
(age -30) ∗male/10	**-.039**	**.016**	**-.10**	**.04**
(age -40) ∗ male ∗ (age>40)/10			**.14**	**.05**
log (weight/2700) ∗ (weight<2700)			**.68**	**.24**
log (weight/2700) ∗ (weight>=2700)			**-.51**	**.16**
constant	**-.34**	**.03**	**-.30**	**.07**

Figures 2.2.2-19 shows that the overall trend of the air bag effect with driver age is slightly increasing for men, as reflected in Model 1 of Table 2.2.2-4. For women, Figure 2.2.2-20, a slightly decreasing trend appears. However, the trend is much flatter than for men, and the regression model did not accept it as even weakly significant. Even the trend for men is not very consistent. Therefore, an additional term for older men was introduced (such a term was also explored for older women, but was found to be not even weakly significant). Allowing a "kinky" weight relation, and a term for older men (which is effectively the same as a kinky age relation) resulted in the Model 2 shown in Table 2.2.2-4.

To illustrate the implications of this model:

- For women in 2,700 lb cars, the air bag reduces the fatality risk by 42%

- For 30 year old men in 2,700 lb cars, the air bag reduces the fatality risk by 30%,
  -for 20 year old men, the reduction is 19%
  -for 40 year old men it is 39%
  -for 50 year old men it is 35%
  -for 60 year old men it is 31%, compared with 46% according to the simpler model

- For a 2,000 lb car, the risk reduction is 25% more than for a 2,700 lb car,
  -for a 2,500 lb car it is 6% more.

- For a 3,000 lb car the risk reduction is 5% more than for a 2,700 lb car,
  -for a 3,500 lb car it is 11% more, and
  -for a 4,000 lb car it is 17% more.

One must keep in mind that this relation may not reflect physical effects of vehicle weight, but could be due to driver and use factor which are correlated with driver age, but are not known.

Such a simple linear model has to be interpreted with extreme caution. For instance, for a woman in a 2,000 lb car it predicts a risk reduction by 30+12+25 = 67% which appears unlikely high.

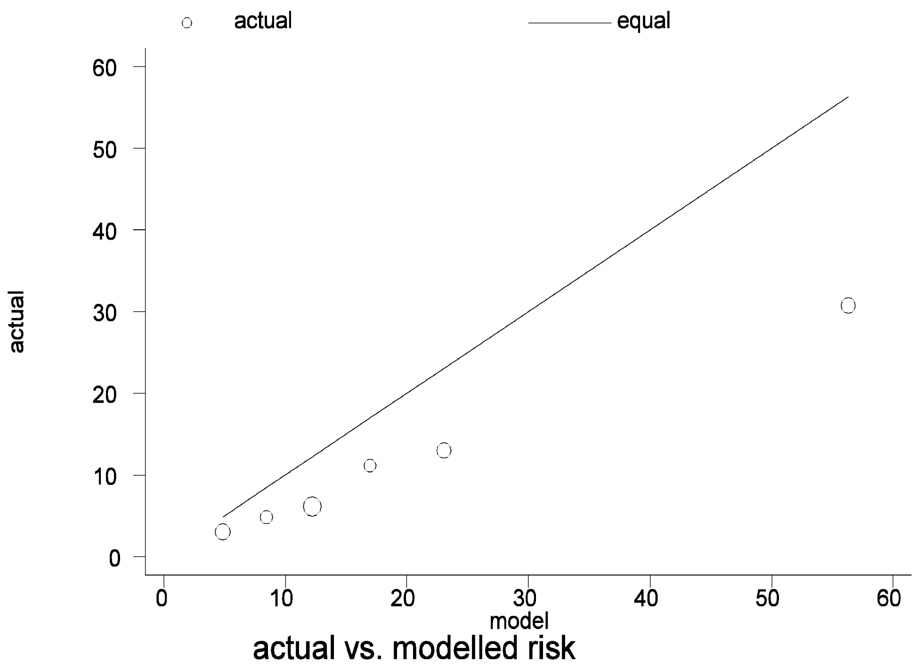


Figure 2.2.2-11 Actual driver fatality risks in air bag cars versus modelled risk for cars without air bags. Single car crashes, frontal impacts.

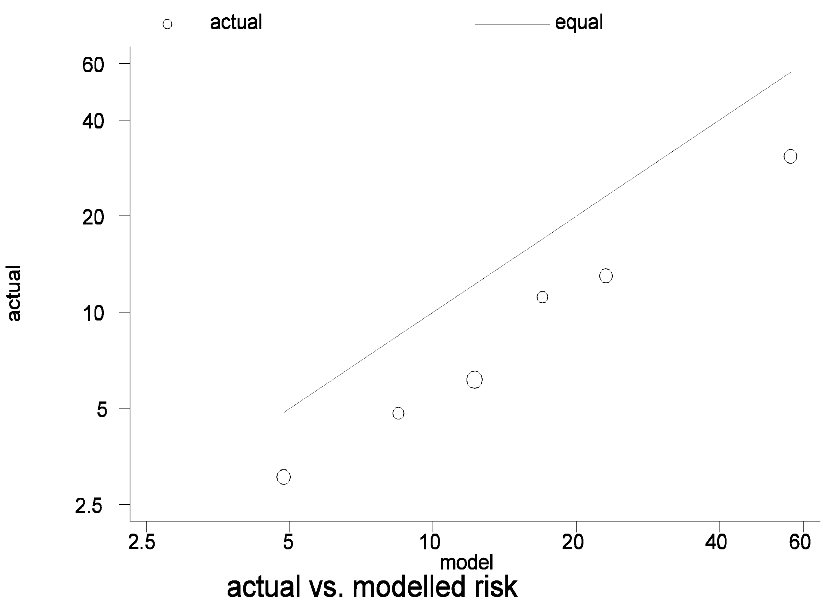


Figure 2.2.2-12 Actual driver fatality risk in air bag cars versus modelled risks for cars without air bags. Single car crashes, frontal impacts. Double logarithmic scales.

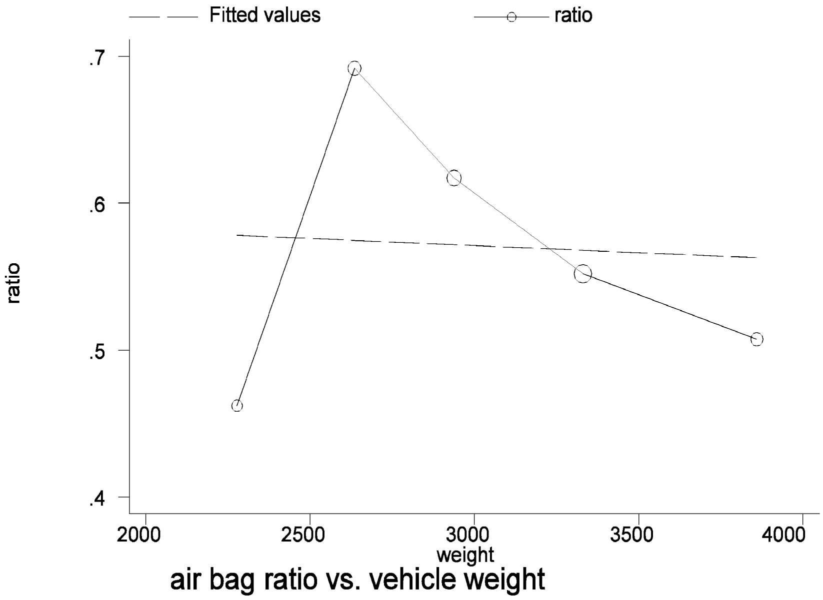


Figure 2.2.2-13 Ratio of driver fatality risks in cars with and without air bags, versus car weight. Single car crashes, frontal impact. The broken line is fitted to the points shown.

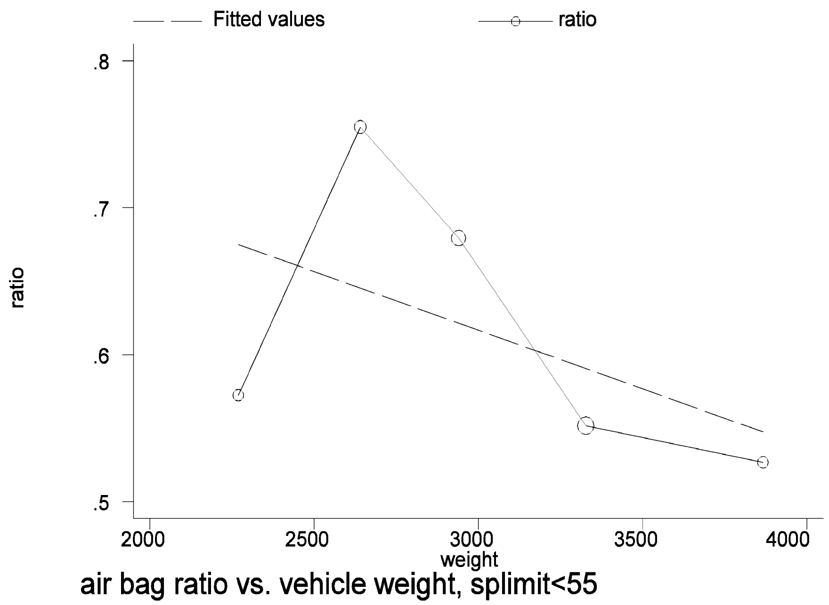


Figure 2.2.2-14 Ratio of driver fatality risks in cars with and without air bags, versus car weight. Single car crashes, frontal impacts, speed limit less than 55 mph. The broken line is fitted to the points shown.

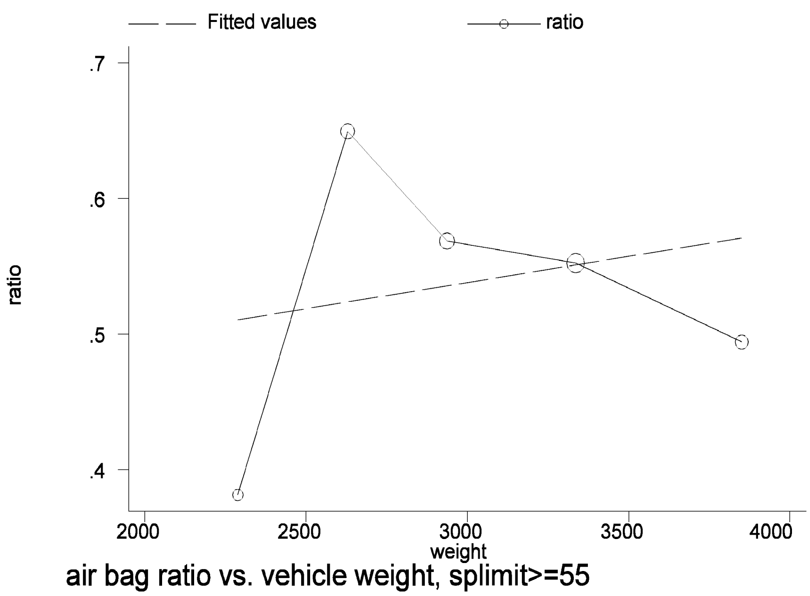


Figure 2.2.2-15 Ratio of driver fatality risks in cars with and without air bags, versus car weight. Single car crashes, frontal impact, speed limit 55 mph or more. The broken line is fitted to the points shown.

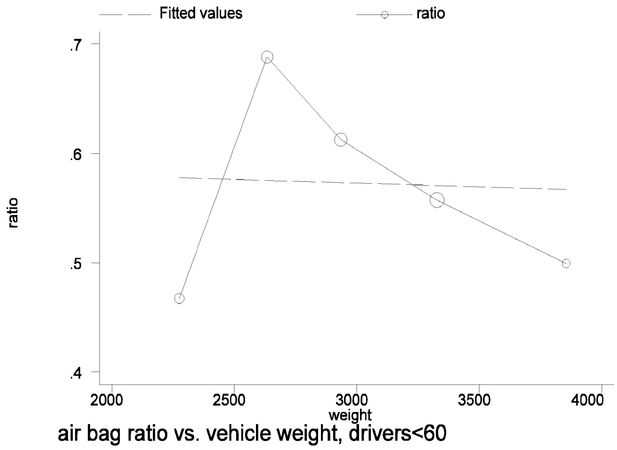


Figure 2.2.2-16 Ratio of driver fatality risks in cars with and without air bags, versus car weight. Single car crashes, frontal impact. Driver under 60 years old.

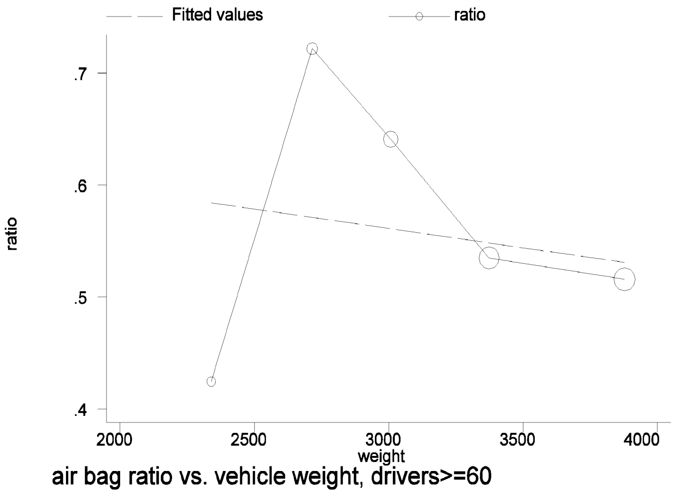


Figure 2.2.2-17 Ratio of driver fatality risks in cars with and without air bags, versus car weight. Single car crashes, frontal impact, speed limit less than 55 mph. Driver 60 or more years old. The broken line is fitted to the points shown.

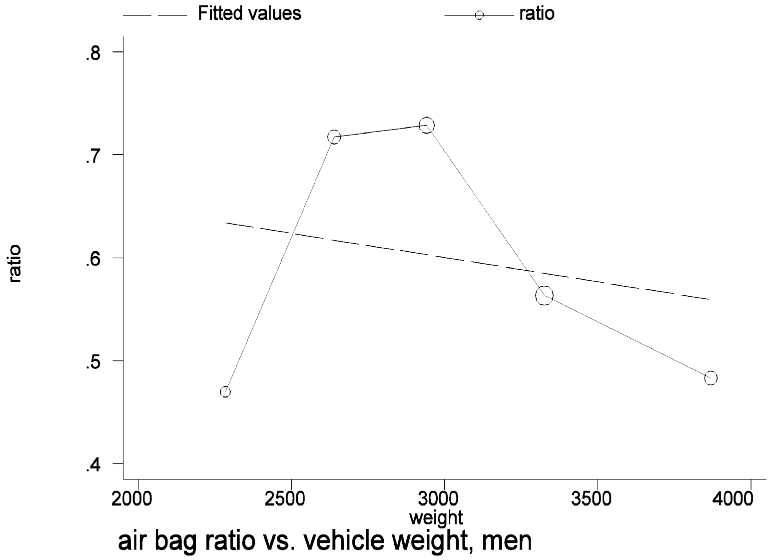


Figure 2.2.2-18 Ratio of driver fatality risks in cars with and without air bags, versus car weight. Single car crashes, frontal impact, speed limit less than 55 mph. The broken line is fitted to the points shown, male driver.

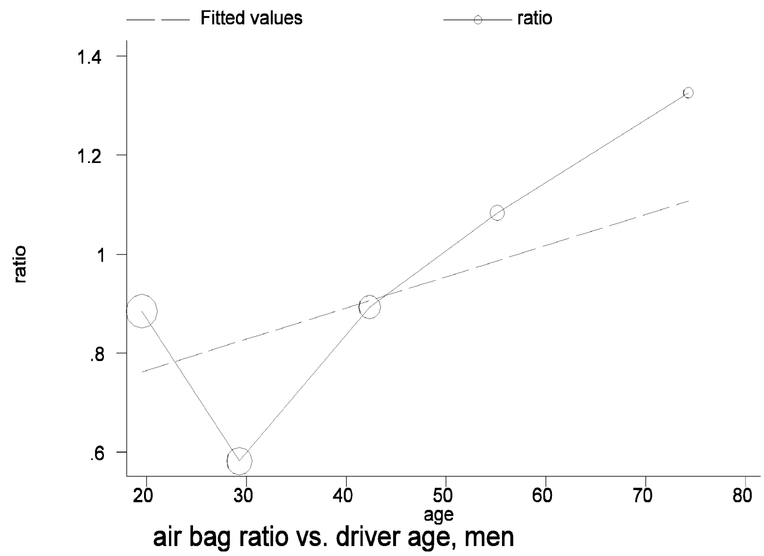


Figure 2.2.2-19 Ratio of driver fatality risks in cars with and without air bags, versus driver age. Single car crashes, frontal impact, male driver.

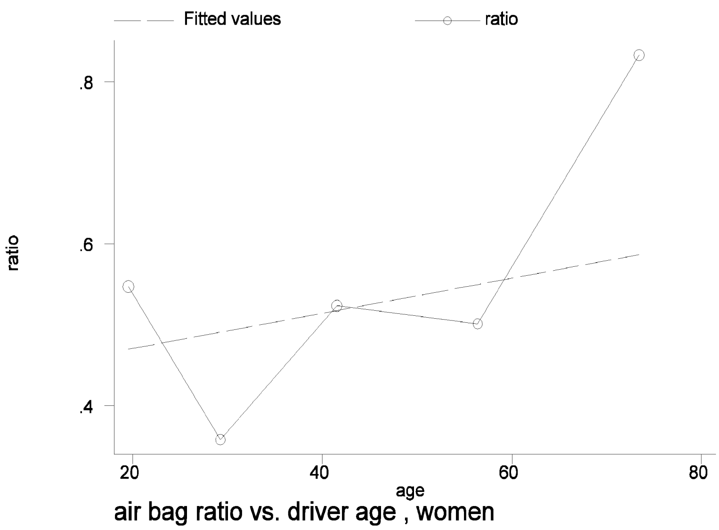


Figure 2.2.2-20 Ratio of driver fatality risks in cars with and without air bags, versus driver age. Single car crashes, frontal impact, female driver.

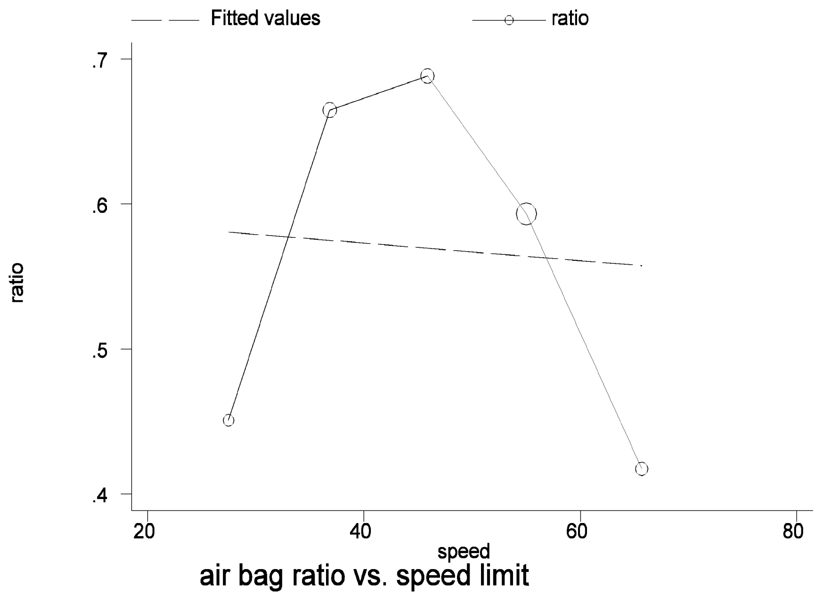


Figure 2.2.2-21 Ratio of driver fatality risks in cars with and without air bags, versus speed limit. Single car crashes, frontal impacts, male drivers. The broken line is fitted to the points shown.

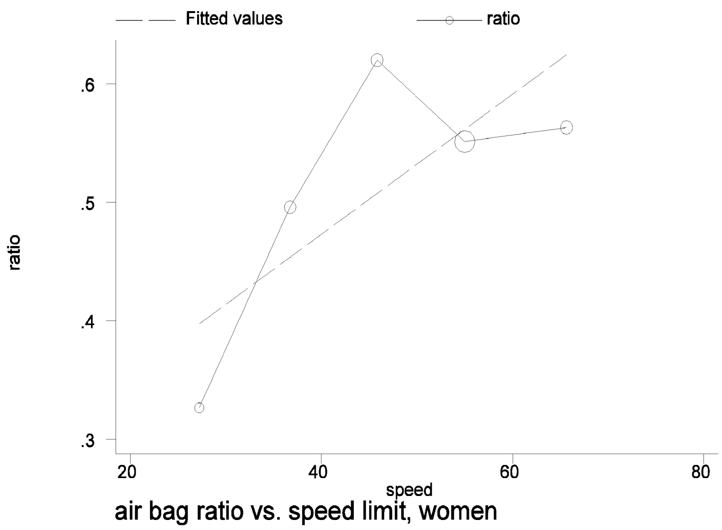


Figure 2.2.2-22 Ratio of driver fatality risks in cars with and without air bags versus speed limit. Single car crashes, frontal impacts, female drivers. The broken line is fitted to the points shown.

2.2.3 Single car crashes with right side impacts

Air bags are designed to deploy in frontal impacts. Therefore, one should not expect them to have an effect in side impacts. This is plausible if, e.g., a car slides sideway into an object. If, however, a car has a forward component of motion when it strikes an object with its side it will be decelerated and, air bags may, and often do deploy, and may have a beneficial effect.

For this analysis, right side impacts were defined by the FARS code 3, and GES code 2. This is not an exact match, but it is not clear whether including the FARS codes 2 and 4 would have resulted in a better match. Some exploratory analyses showed that it made very little difference in the result.

Table 2.2.3-1 shows the numbers of cases which could be used for the analysis. They are much smaller than the numbers available for the analyses in the previous sections. The cross-product ratio is 0.80, providing a very crude estimate of an air bag effect of a 20% fatality risk reduction. This is more than the final estimate of 11% shown in Table 2.2.3-3.

Table 2.2.3-1 Case numbers for single car crashes with right-side impacts.

cars with	FARS	GES
no air bag	706	1185
air bag	369	774

Table 2.2.3-2 shows the coefficients of the model obtained for the driver fatality risk in cars with no air bags. Noteworthy is that no overall term in vehicle weight was necessary or useful to represent the data. Only a term for weight in excess of 3,300 lb appears. It would not be significant by conventional standards, but those criteria are not relevant in this context, because the term applies directly only to a small part of the population. It was retained because it improved the model fit noticeably. The other weight term applies only to female drivers. While usually logarithmic terms of the weight represented the data better, in this case a linear term in weight was clearly better. Another weight related term is an age term which applies only to cars over 3,100 lb. It is less than its estimated error, but it improves the fit of a few data points noticeably.

Figure 2.2.3-1 shows the actual risks versus those modelled. Because especially in the following figures, some points are based on very low case numbers, points were represented in a special way. The numerical value of a symbol is the smaller of the numbers of FARS and of the GES cases on which the risk estimate is based. That gives a very rough idea of the numerical reliability of that point. The size of the font is approximately proportional to the number of deaths represented by the point. It reflects the "importance" of that point from a societal point of view.

The overall agreement between the actual values and the model in Figure 2.2.3-1 is very good.

Figure 2.2.3-2 shows the actual and modelled risks versus car weight. The points are well represented, even the two right most points, due to the term for weight over 3,300 lb. If one ignores the point for the heaviest vehicles, identified by the small case number of 19, the points show only a very weak, if any, downward trend.

Table 2.2.3-2 Model coefficients for the driver fatality risk in cars without air bags in single car crashes, right side impacts.

variable	coefficient	non-standard error
female ∗ (splimit = 55)	.70	.18
(splimit -50)/10	.28	.09
(splimit >55)	-.60	.36
female	-1.32	.21
female ∗ (weight - 2,800)/1,000	.74	.22
Log (weight/3,300) ∗ (weight >3,300)	-3.08	1.87
(age - 20) ∗ (age<20) ∗ male	.15	.05
(age - 30) ∗ (weight>3,100)/10	-.076	-.085
constant	-4.92	.18

Figures 2.2.3-3 and 4 show the actual and modelled risks versus car weight separately for male and female drivers. The contrast is noticeable: without the right-most point, no trend is suggested for male drivers, whereas for female drivers a trend is clear, even without the rightmost point. This is reflected by the interaction term sex $*$ vehicle-weight in the model.

Figures 2.2.3-5 and 6 show the actual and modelled risks versus car weight by speed limit. For speed limits less than 55 mph practically no trend, and an isolated outlier is apparent. For speed limits of 55 mph or higher, a clear downward trend is present, with the exception of the extreme right point which is based on very few cases. It is interesting to note that these patterns are not reflected by an interaction term of weight and speed limit. These patterns are adequately described by the other variables, some of which are correlated with speed limit. If one introduces interaction terms of weight and speed limit, they do not even approach customary significance levels.

Figures 2.2.3-7 and 8 show very different relations between the actual risk and age for men and women. For men, a clear trend from 20 to 50 years of age appears, the points for higher ages being based on only few cases. For women, no clear trend appears. The model represents the overall trends in general, but it fails to capture the clear trend for male drivers. Adding a simple age term for male drivers under 50, or more complicated age and sex interaction terms does not help.

Similar patterns appear for other disaggregations: for car weights of 2,800 lb or less, and for speed limits under 55 mph, clearly increasing trends up to age 50 are apparent, but for weights over 2,800 lb, and for speed limits of 55 mph or more, the risks remain practically constant in this age range (the graphs are not shown). Because of these systematic deviations, the model can not be considered fully satisfactory, despite of the good overall fit.

Figure 2.2.3-9 shows the actual and modelled risks versus speed limit. There are no systematic differences between the model and the data. The same holds when the cases are disaggregated by men/women, low/high car weight, or low/high speed limit. These graphs are not shown.

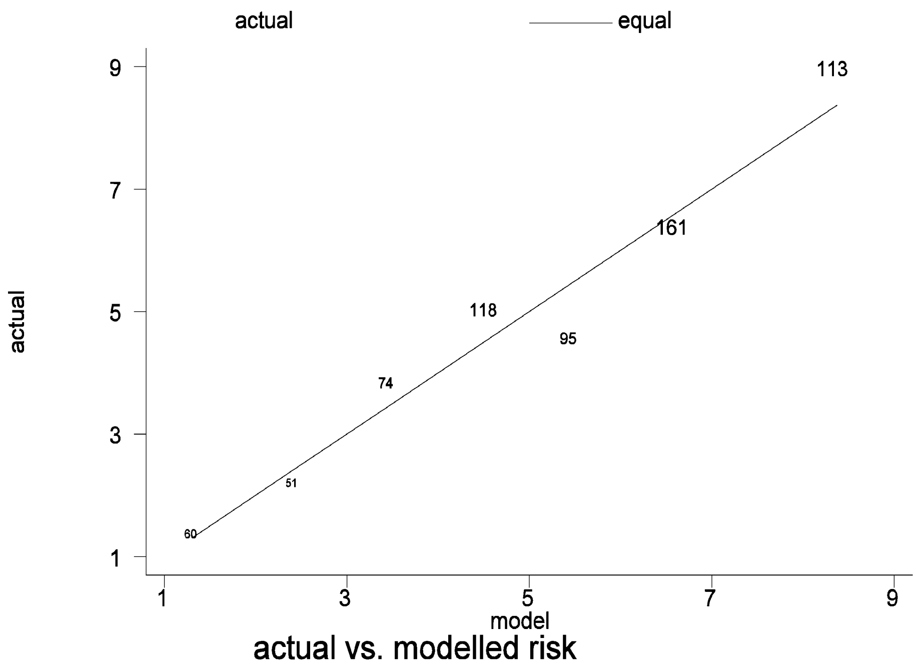


Figure 2.2.3-1 Actual versus modelled driver fatality risk in single car crashes, right side impact, no air bag. The numbers show the smaller of the numbers of FARS, and of GES cases on which the risks are based; the font size is approximately proportional to the number of deaths represented.

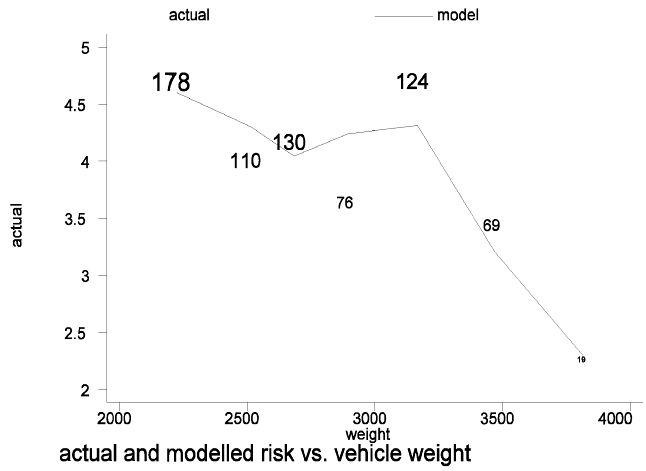
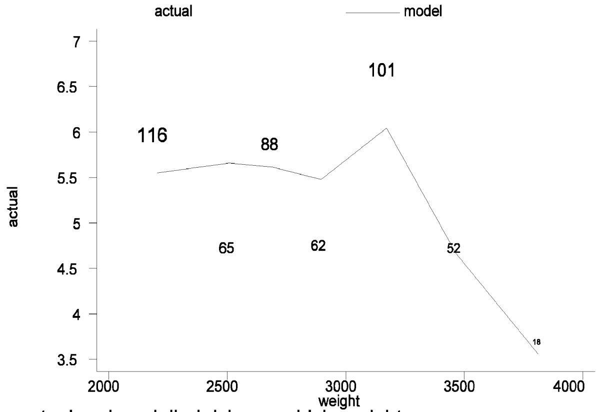
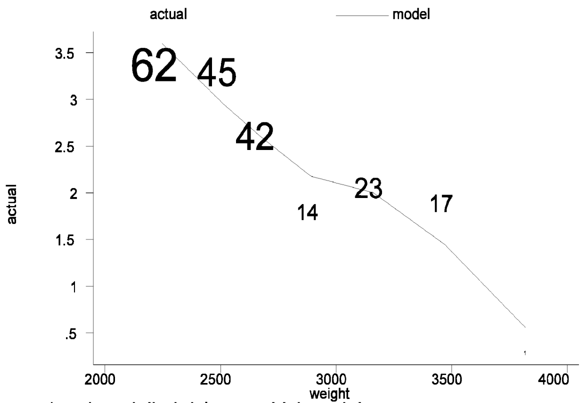


Figure 2.2.3-2 Actual and modelled driver fatality risks versus car weight. Single car crashes, right side impact, no air bags.



actual and modelled risk vs. vehicle weight, men

Figure 2.2.3-3 Actual and modelled driver fatality risk versus car weight for male drivers. Single car crashes, right side impact, no air bag.



actual and modelled risk vs. vehicle weight, women

Figure 2.2.3-4 Actual and modelled driver fatality risk versus car weight for female drivers. Single car crashes, right side impact, no air bag.

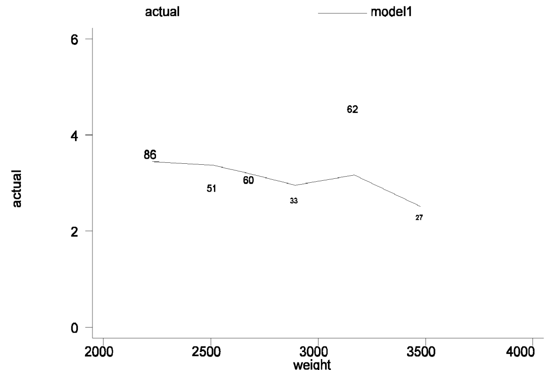


Figure 2.2.3-5 Actual and modelled driver fatality risk versus car weight, speed limit <55 mph. Single car crashes, right side impacts.

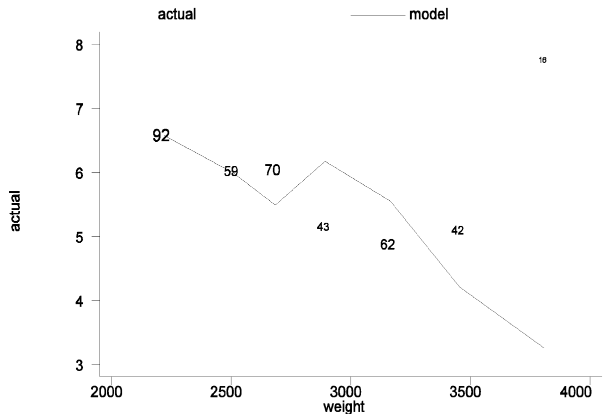


Figure 2.2.3-6 Actual and modelled driver fatality risk versus car weight, speed limit >=55 mph. Single car crashes, right side impacts.

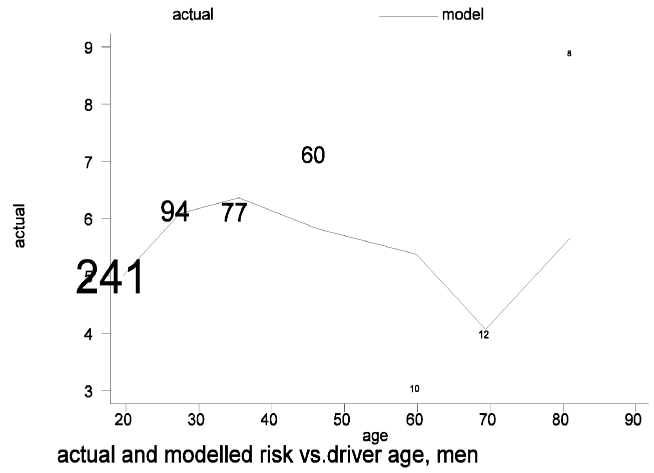


Figure 2.2.3-7 Actual and modelled driver fatality risk versus driver age, male driver. Single car crashes, right side impact.

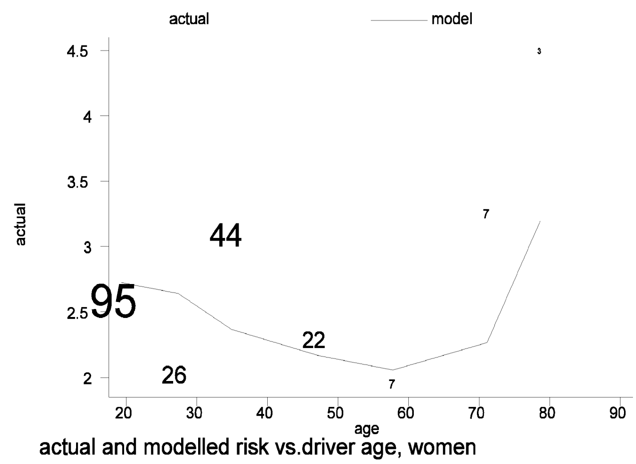


Figure 2.2.3-8 Actual and modelled driver fatality risk versus driver age, female drivers. Single car crashes, right side impact.

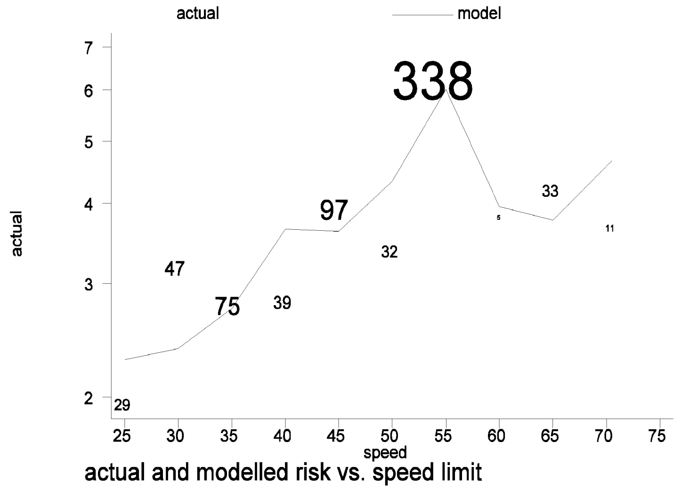


Figure 2.2.3-9 Actual and modelled driver fatality risk versus speed limit. Single car crashes, right side impact.

This model was used to predict for drivers in air bag cars the fatality risk they would have faced if their cars had not had air bags. Figures 2.2.3-10 and 11 show the actual versus the predicted risks. Figure 2.2.3-10 shows that up to predicted risks of 5/1,000, actual and predicted risks are practically equal. Above this level, the actual risks are clearly lower than the predicted risks. In the double-logarithmic scale of Figure 2.2.3-11, the same pattern appears. However, here it appears equally plausible that the data points fall around a straight line less steep than that representing equality.

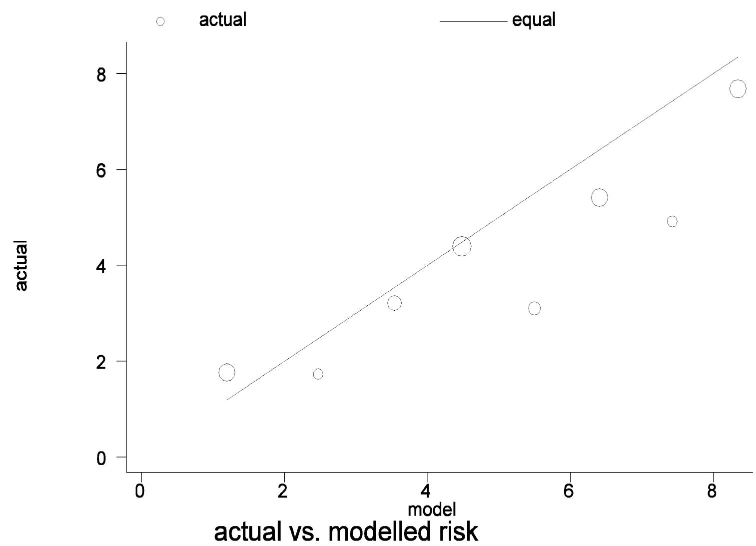


Figure 2.2.3-10 Actual driver fatality risks in air bag cars versus risk modelled for cars without air bags. Single car crashes, right side impact.

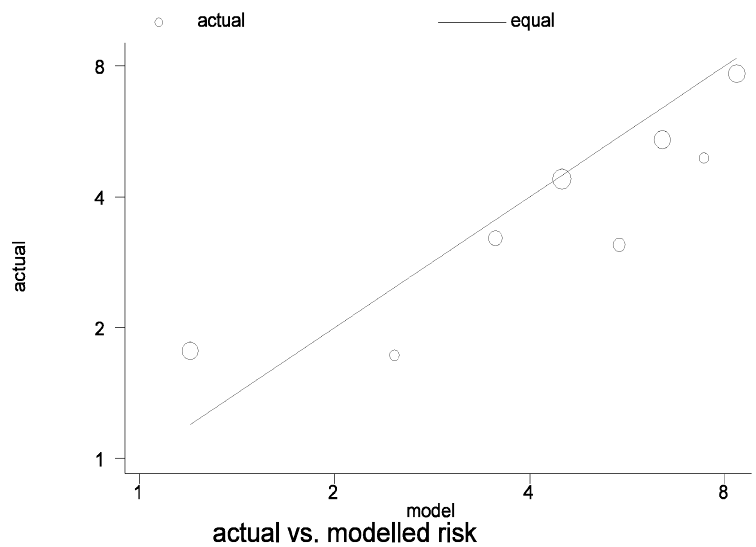


Figure 2.2.3-11 Actual driver fatality risk in air bag cars versus risk modelled for cars without air bags. Single car crashes, right side impacts. Double logarithmic scales.

Table 2.2.3-3 shows estimates of the overall effect of air bags. The overall estimate is 11%, but with an estimated error of 13; thus the apparent effect might reflect just random fluctuations. The average of the effectiveness estimates based on the value of (actual-predicted)/predicted for the individual cases shows negative air bag effect, but with a much larger error. This is not surprising because of the dichotomy apparent in Figure 2.2.3-10: there is a subset of cases where (actual-predicted)/predicted has the expected value zero, and the complementary set where it has a value of the order of
-0.2.

Table 2.2.3-3 Driver fatality risk reduction in cars with air bags relative to the model for cars without air bags (percent). Single car crashes, right side impacts. Non-standard errors are in parentheses. Negative signs indicate a risk increase.

estimated as	all cars with air bags	cars with only driver air bag
reduction of total deaths	11 (13)	13 (12)
average reduction of fatality risks	-8 (17)	-3 (14)

Figures 2.2.3-12, 13, and 14 show the actual and predicted risks versus car weight, driver age, and speed limit. There appears to be a roughly 20% risk reduction for the lighter cars, but more for the heavier cars, and a similar reduction for the higher speed limit, but more for the lowest. With regard to driver age, the picture be less clear: for ages under 50, there is a clear risk reduction, but for the higher ages the two points differ too much to allow more than the speculation that there might be no difference. The more detailed graphs show no clear patterns and are not reproduced. That any air bag effect seems to be higher in lighter cars than in heavier cars, and higher at higher speed limits, agrees with the pattern of Figures 2.2.3-10 and 11 that air bags seem to have an effect only in situations with high risks - or at least, that the effect is greatest in situations with high risks, and declines as the risk decreases.

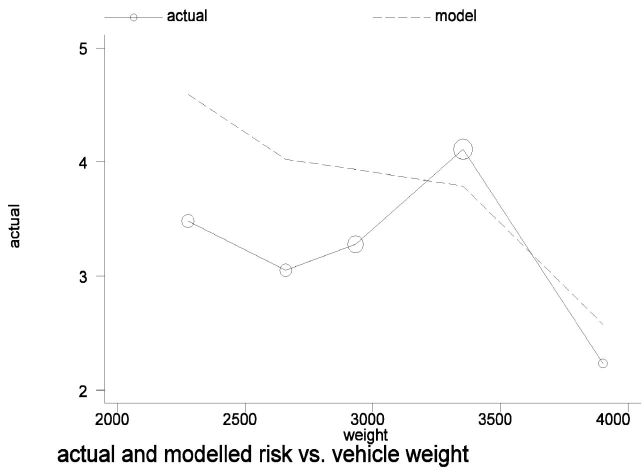


Figure 2.2.3-12 Actual driver fatality risk in air bag cars and risk modelled for cars without air bags versus car weight. Single car crashes, right side impact.

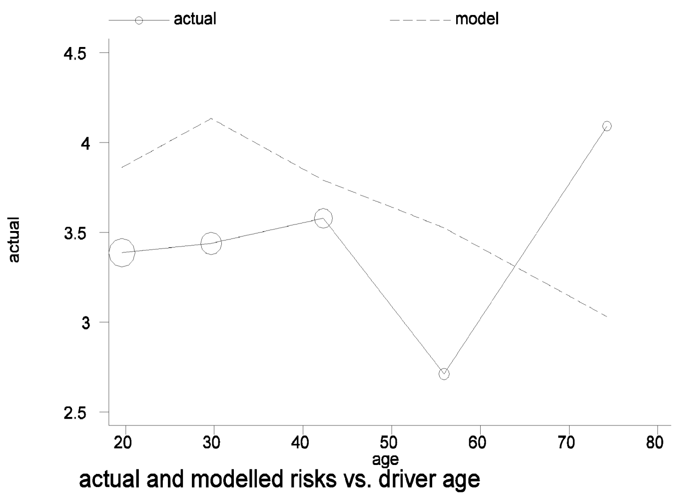


Figure 2.2.3-13 Actual driver fatality risk in air bag cars, and risk expected in non-air bag cars, versus driver age. Single car crashes, right side impact.

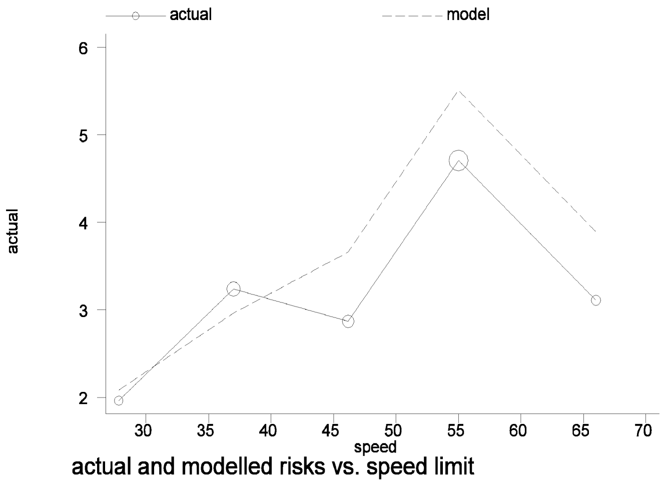


Figure 2.2.3-14 Actual driver fatality risk in air bag cars, and risk expected in non-air bag cars, versus speed limit. Single car crashes, right side impact.

Therefore, attempts to study how air bag effects depend on the several factor used, as in sections 2.2.1 and 2 gave largely meaningless result, and were abandoned.

Instead, simple estimates were made for several disaggregations of the cases: low-risk/high-risk, light-cars/heavy-cars, low-age/high-age, and low-speed/high-speed. These results are shown in Table 2.2.3-4. First, one notices that estimates relying on the individual values (actual-predicted)/predicted, E2, give in most cases implausibly high negative effects. They were therefore ignored. The estimates based on total actual deaths/total predicted deaths show the same pattern observed when looking at Figures 2.2.3-10 through 14: air bags have a beneficial effect in high risk situations, none in low risk situations. However, the effect of 23 or 24% would be considered “significant” only for risks of 5/1,000 or higher, and marginally “significant” (8%) for light cars.

Table 2.2.3-4 Driver fatality risk reduction in cars with air bags relative to the model for cars without air bags, in percent. Single car crashes, right side impacts. E1 are estimates 1 - (actual driver deaths)/(expected driers deaths), E2 are averages of (1 - death/risk), calculated for each case. Negative signs indicate a risk increase.

subsets of case	E1	E2
risk < 5/1000	-2 (16)	-22 (22)
risk >= 5/1000	23 (11)	24 (11)
men	13 (12)	12 (13)
women	1 (20)	-30 (28)
age < 40 years	15 (12)	- 2 (18)
age > = 40 years	1 (20)	-26 (22)
weight < 2,800 lb	24 (14)	20 (15)
weight > = 2,800 lb	4 (14)	-22 (20)
speed limit <55 mph	6 (15)	-6 (19)
speed limit >=55 mph	16 (15)	-11 (21)

While this leaves the benefit of air bags in right side impacts doubtful, it still raises doubts about using right side impacts as a comparison basis for estimating air bag effectiveness in other impacts, by assuming that their effect in right side impacts is zero. This could result in an underestimation of air bag effectiveness in other impacts. Even more likely, it will distort estimates of air bag effectiveness in relation to vehicle, driver and other pre-crash factors.

2.2.4 Single car crashes with left side impacts

In single car crashes with left-side impacts, one would expect even less an air bag effect than in those with right side impacts, because if occupant compartment intrusion occurs, a front air bag will not protect against it. However , if there is no intrusion, and if the car has a forward component of motion when it impacts an object on its left side, an air bag may deploy and have some beneficial effect.

For this analysis, left side impacts were defined by the FARS code 9, and the GES code 3.

The numbers of cases which could be used are shown in Table 2.2.4-1. Comparing them with those of table 2.2.3-1 for right side impacts, one notices that the numbers of GES cases are comparable, but that the number of FARS cases are nearly double, reflecting the higher fatality risk in left side impacts, compared with right side impacts. The cross-product ratio of 0.92 provides a very rough estimate of an air bag effect of 8%, compared with a similar estimate of 20% for right side impacts. These estimates, however, are speculative and possibly biased, as mentioned before. Estimates controlling for the confounding effects are shown in Table 2.2.4-3. There, an estimate of 19% corresponds to the crude estimate of 8%.

Table 2.2.4-1 Case number for single car crashes with left-side impacts

cars with	FARS	GES
no air bags	1246	1061
air bags	757	698

Modelling the fatality risk proved very difficult, because it did not show the fairly smooth relations with car weight, driver age, and speed limit which appeared in the other crash configurations. Without including implausible high order interaction terms, the actual risks could not be adequately approximated. Therefore, a different approach was used. The continuous variables were categorized. After some experimenting, car weight was categorized as -2,200-2,600-3,000-3,400-lb, driver age as -25-30-40-60- years, and speed limit as -35-50,55,60- mph. The corresponding categorical variables, together with driver sex, and interactions were used in modelling. Initially, interactions of any two variables were allowed to enter the model. After initial models had been developed, interactions of three variables were allowed, and one of them retained. Table 2.2.4-2 shows the coefficients of the resulting model. That for (weight <2,200 lb) would not be considered “significant” by conventional standards, but it improved the fit of some data points noticeably.

Though the model represents the actual risks very well overall, it does so by using categorical variables which do not appear to approximate smooth and physically plausible relations. The examination of the disaggregated graphs showed that the model fails to capture certain patterns with regard to the continuous variables underlying the models. Therefore, the model should be used with extreme care, and any conclusions based on it considered speculative.

Table 2.2.4-2 Model coefficients for the driver fatality risk in cars without air bags in single car crashes, left side impacts.

variable	coefficient	non-standard error
female	**-2.01**	**.36**
(weight < 2,200)	**.40**	**.23**
(3,000 <= weight < 3,400)	**.34**	**.12**
female ∗ (splimit < 35)	**.45**	**.12**
(splimit < 35)	**-.85**	**.30**
(splimit > 55)	**-.78**	**.29**
(3,000 <= weight < 3,400) ∗ (35<=splimit<55) ∗ (25 <=age<40)	**1.59**	**.40**
constant	**-4.39**	**.16**

Figure 2.2.4-1 compares the actual and the modelled risks. Because in the following more detailed presentations some apparent outliers are based on very few cases, a special form of presentation was used. Each "point" is represented by a numeral. Its numerical value is the smaller of the numbers of the FARS, and of the GES cases from which the risk is calculated. This provides some intuitive perception of the statistical precision of that point. The font size is approximately proportional to the total number of driver deaths represented by the point. This reflects the importance of that point. The actual and modelled risks shown in Figure 2.2.4-1 agree very well, even where the points are based on only few cases.

However, with a categorical model it is always possible, by adding enough terms to achieve a perfect fit. In this case, the model has 10 coefficients, and the figure has 9 data points. Therefore, the possibility of this occurring was explored further.

A categorical model can predict only a limited number of different values for the risk. In this case, 23 values were possible. Figure 2.2.4-2 shows the actual risks for the 23 groups formed by the cases for which the model gave the same risk, versus these risks. Again, as in Figure 2.2.4-1 the agreement between actual and modelled risks is very good. Only a few points based on very few cases deviate appreciably from this line.

This representation allows also to assess the importance of terms in the model. The points with risks of about 30 and 80, represented by "3" and "4", are the only ones relying on the triple interaction term. Without it, there would be a systematic deviation, though it would be small: the points would be shifted at most by 1.6 to the left. The triple interaction term includes the weight range 3,000 to 3,400 lb, which contains some sporty cars, e.g., the Camaro, with young drivers.

The group represented by the large "292" is based on 292 GES and 467 FARS cases. It comprises cases with male drives of cars in the weight ranges 2,200-3,000, or over 3,400 lb, on roads with speed limits between 35 and 55 mph.

Figure 2.2.4-3 shows the actual and modelled risks versus car weight. A strange pattern appears: an increasing trend from 2,400 to 3,200 lb, but reversals at the low and high end. It appears well represented by the model. This, however, is not surprising: the high point at 3,200 lb is fitted by the categorical term for weights between 3,000 and 3,400 lb, and the also high point near 2,000 lb by the categorical term for weights under 2,200 lb.

This makes it unlikely that these terms reflect effects of physical weight. Several car models with a sporty image fall into the weight range 3,000-3,400. They might attract drivers whose driving style increases the fatality risk in a crash.

Corresponding graphs disaggregated by other variables show similar patterns, with the following exceptions concerning the point near 2,000 lb. For older drivers, the risk is higher, for younger drivers, it is lower than the modelled risk. For men the risk is higher, for women lower than the modelled risk. However, these systematic deviations could not be represented by simple interaction terms.

The model did not well represent the relations with regard to driver age, Figures 2.2.4-6 and 5. For men, the data show a strongly increasing trend from 20 to 35 years; this trend could not be represented by adding weight terms and interactions with weight. For women, there is no apparent relation between risk and age; the model fails badly to approximate the point "65".

Figures 2.2.4-6 and 7 show separate relations for low and high speed limits. There is a striking difference: at low speed limits, the risk varies relatively little among ages up to 40 years; at high speed limits there is a very strong, consistent increase up to the point at 50 years. The model fails completely to capture this trend.

Figures 2.2.4-8 and 9 show actual and modelled risks versus speed limit. They show a pattern of an inverted "U" which is reasonably well represented by the model, thanks to categorical terms for the lowest and the highest speed limits. However, the model fails to capture a striking feature of Figure 2.2.4-9 for female drivers: the nearly linear increase of the risk with the speed limit up to 55 mph.

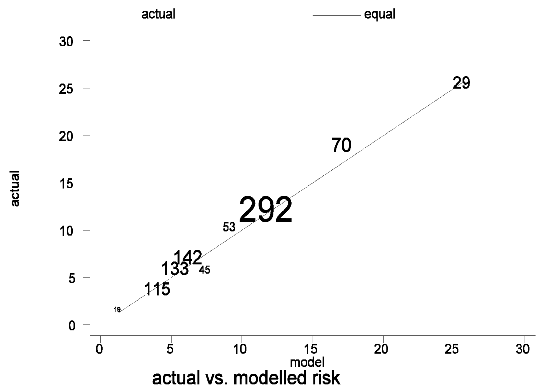


Figure 2.2.4-1 Actual versus modelled driver fatality risk (per 1,000 involvements) in single car crashes, left side impacts. Cars with no air bags. The number representing a data point is the smaller of the numbers of FARS cases, and GES cases from which the risk is calculated. The size of the font is approximately proportional to the number of driver deaths represented by the point.

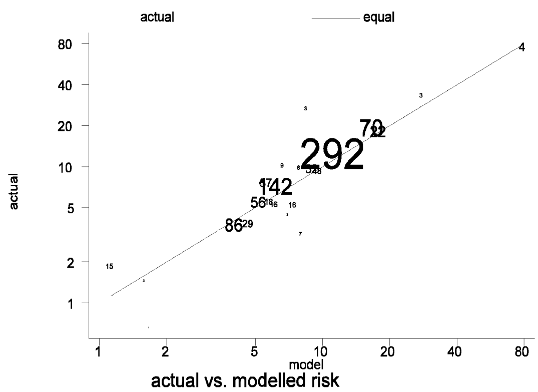


Figure 2.2.4-2 Actual versus modelled driver fatality risk (per 1,000 involvements) in single car crashes, left side impacts. Cars with no air bags. Each point represents the cases for which the model predicted exactly the same risk. The number representing a data point in the smaller of the numbers of FARS cases, and GES cases from which the risk is calculated. The size of the font is approximately proportional to the number of driver deaths represented by the point.

The following points may not be recognizable on all prints or reproductions:

model	actual	number
1.58	1.46	3
1.67	0.66	1
6.97	4.45	2

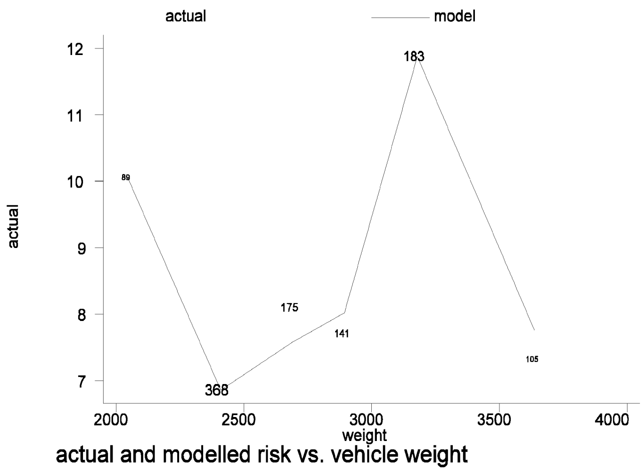


Figure 2.2.4-3 Actual and modelled driver fatality risk (per 1,000 involvements) versus car weight. Single car crashes with left side impacts. Cars with no air bag. The number representing a data point in the smaller of the numbers of FARS cases, and GES cases from which the risk is calculated. The size of the font is approximately proportional to the number of driver deaths represented by the point.

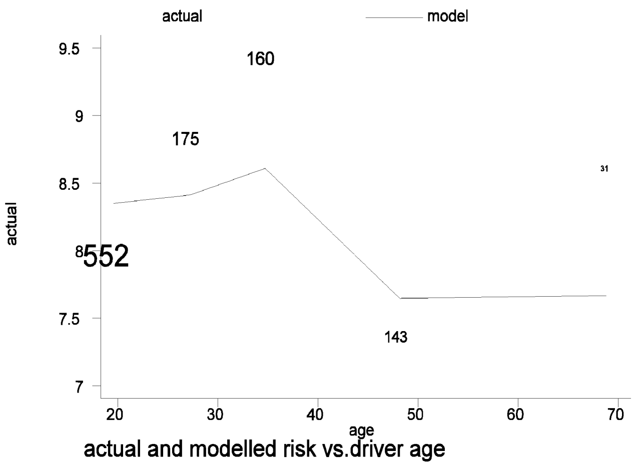
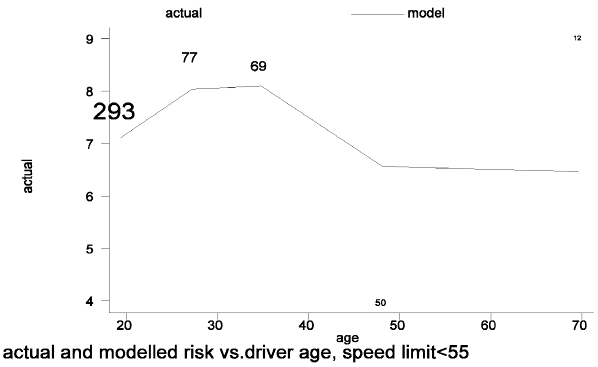
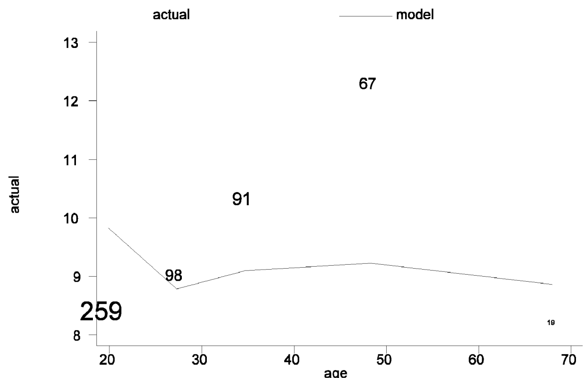


Figure 2.2.4-4 Actual and modelled driver fatality risk (per 1,000 involvements) versus driver age. Single car crashes with left side impacts. Cars with no air bags. The number representing a data point in the smaller of the numbers of FARS cases, and GES cases from which the risk is calculated. The size of the font is approximately proportional to the number of driver deaths represented by the point.



actual and modelled risk vs.driver age, speed limit<55

Figure 2.2.4-5 Actual and modelled driver fatality risk (per 1,000 involvements) versus driver age. Single car crashes with left side impact, speed limit < 55 mph. Cars with no air bag. The number representing a data point in the smaller of the numbers of FARS cases, and GES cases from which the risk is calculated. The size of the font is approximately proportional to the number of driver deaths represented by the point.



actual and modelled risk vs.driver age, speed limit>=55

Figure 2.2.4-6 Actual and modelled driver fatality risk (per 1,000 involvements) versus driver age. Single car crashes, left side impact, speed limit > = 55 mph. Cars with no air bags. The number representing a data point in the smaller of the numbers of FARS cases, and GES cases from which the risk is calculated. The size of the font is approximately proportional to the number of driver deaths represented by the point.

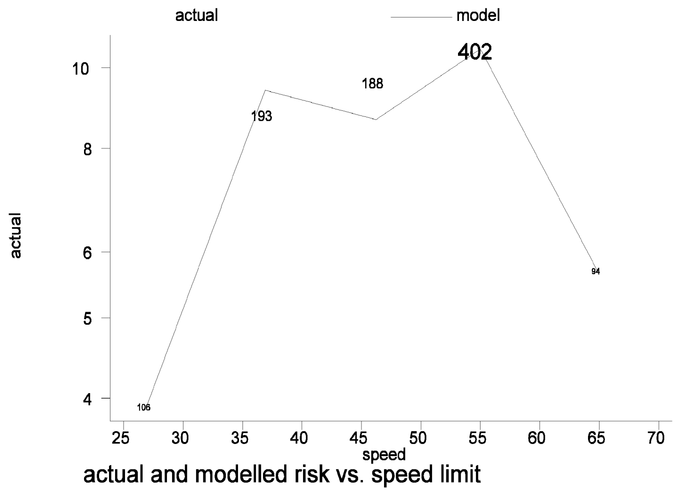


Figure 2.2.4-7 Actual and modelled driver fatality risk (per 1,000 involvements) versus speed limit. Single car crashes, left side impact. Cars with no air bag. The number representing a data point in the smaller of the numbers of FARS cases, and GES cases from which the risk is calculated. The size of the font is approximately proportional to the number of driver deaths represented by the point.

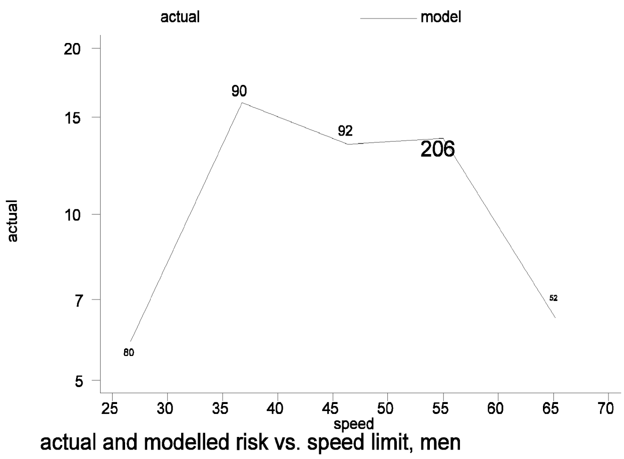


Figure 2.2.4-8 Actual and modelled driver fatality risks (per 1,000 involvements) versus speed limit, male drivers. Single car crashes, left side impact. Cars with no air bag. The number representing a data point in the smaller of the numbers of FARS cases, and GES cases from which the risk is calculated. The size of the font is approximately proportional to the number of driver deaths represented by the point.

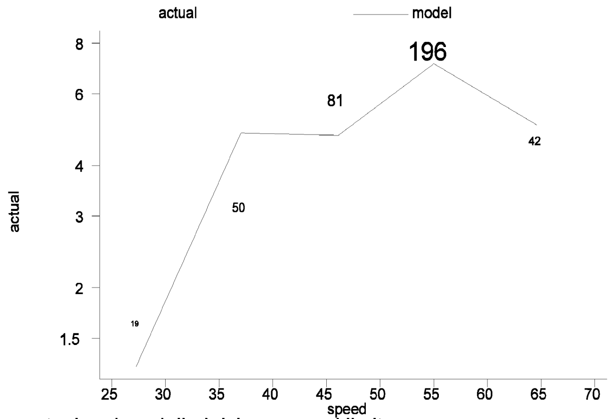


Figure 2.2.4-9 Actual and modelled driver fatality risks (per 1,000 involvements) versus speed limit, female drivers. Single car crashes, left side impacts. Cars with no air bag. The number representing a data point in the smaller of the numbers of FARS cases, and GES cases from which the risk is calculated. The size of the font is approximately proportional to the number of driver deaths represented by the point.

The model was used to predict for cars with air bags. What the driver fatality risk would have been if the car had not had an air bag. The overall effectiveness estimates shown in Table 2.2.4-3 are difficult to interpret. The average reduction of the fatality risk is negative for all cars with air bags, positive for cars with only driver air bags, and both are much smaller than their non-standard errors. The most plausible conclusion is that there is no overall beneficial effect of the air bag. However, for all cars with air bags, and for cars with only driver air bags the same beneficial effect of about 20% (though not "significant") appears. The only consistent explanation of both observations is that air bags have in left side impact a beneficial effect in some crashes, a detrimental effect in others, and that the beneficial effect holds only for the higher risk crashes.

Table 2.2.4-3 Driver fatality risk reduction in cars with air bags relative to the model for cars without air bags (percent). Single car crashes, left side impacts. Non-standard errors. Negative signs indicate a risk increase.

estimated as	all cars with air bags	cars with only driver air bags
reduction of total deaths	19 (11)	20 (14)
average reduction of fatality risks	-5 (14)	9 (15)

Figure 2.2.4-10 shows the actual risks in the cars with air bags versus those predicted by the model. Up to a predicted risk of 15/1,000, there are only small and no systematic differences between the actual and predicted risks. For predicted risks between 15/1,000 and 20/1,000, a risk reduction by the air bags is suggested, and for predicted risks over 20, a very large reduction appears.

The cases with predicted risks over 20/1,000 all involve the triple interaction term. This raises the question whether inclusion of this term in the model used for the prediction could have caused the dramatic apparent effect. This is not likely, since omission of this term would not have changed the predicted values very much, as discussed above.

The other point where a risk reduction appears, representing cases with predicted risks between 15/1,000 and 20/1,000, represents cases where only the weight terms of the model are active: most are cars with weight between 3,000 and 3,400 lb, very few with weight under 2,200 lb. However, these weight terms affect, together with other factors, several other points. Thus, their potential influence is unlikely to be obvious.

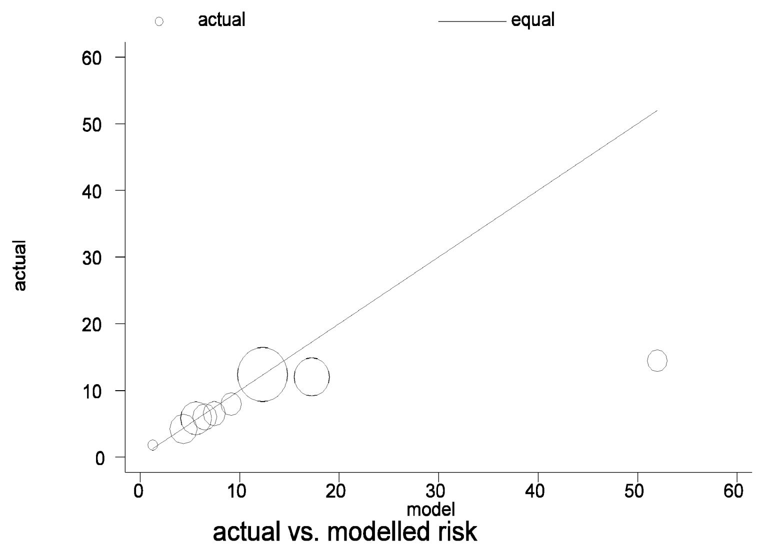


Figure 2.2.4-10 Actual driver fatality risk in air bag cars versus risk modelled for cars without air bags. Single car crashes, left side impact.

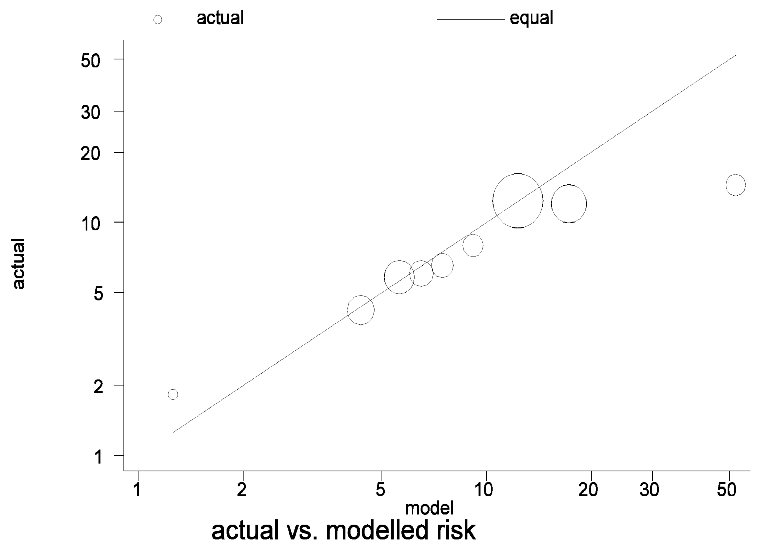


Figure 2.2.4-11 Actual driver fatality risk in air bag cars versus risk modelled for cars without air bags. Double logarithmic scales.

It supports the pattern recognizable in some of the graphs. There is a clear risk reduction for the high risk cases, but no consistent pattern for the other factors: while some overall reductions of deaths would be “significant”, the corresponding average risk reductions are not. Noteworthy is that for lighter cars a detrimental - though not “significant” - effect appears in both measures.

In sum, it appears that in some left side impacts air bags might have a beneficial effect. However, since in others it seems to have a detrimental effect for which there is no plausible reasons, such a conclusion is speculative.

Figures 2.2.4-12 through 25 support this conclusion. With regard to car weight, Figures 2.2.4-12 through 17, the two lightest car groups with air bags have higher driver fatality risks than to be expected for cars without air bags. For the other weight groups, no air bag effect or a beneficial effect appears. In most figures no smooth trend with car weight appears, but rather a suggestion of a step function.

An exception to this pattern holds for women (Figure2.2.4-18): the points scatter widely, and no trend with car weight is apparent.

With regard to driver age (Figures 2.2.4-19 and 20), the patterns for men and women are very similar. For ages around 30 years, air bags reduce the risk by roughly 40%; for younger ages much less. With age increasing beyond 30, air bag effectiveness declines, and for the highest ages their effect seems to be detrimental.

With regard to the speed limit (Figures 2.2.4-21 through 25), the effects appear to be largest for 45 and 50 mph, and less for higher and lower speed limits. Separating younger and older drivers, a strange pattern appears: there is no clear trend, but possibly a U-shaped pattern for younger drivers, but an overall worsening trend with speed limits for older drivers.

If one separates the data by vehicle weight (Figures 2.2.4-24 and 25), again no trend with the speed limit appears, but rather U-shaped relations (and also the pattern observed above, that the air bag effect appears to be mainly detrimental for lighter cars, and beneficial for heavier cars).

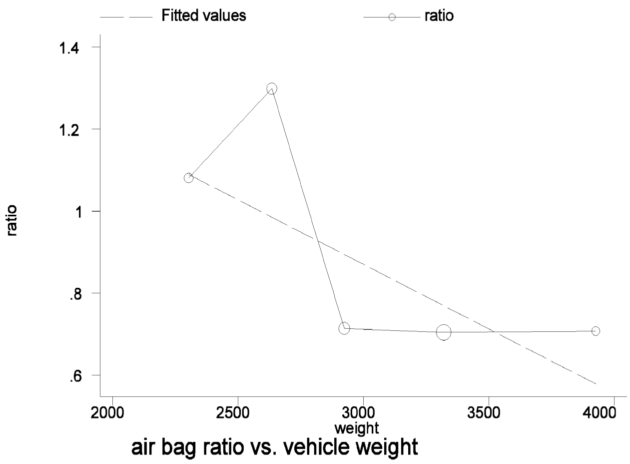


Figure 2.2.4-12 Ratio of driver fatality risks in cars with and without air bags, versus car weight. Single car crashes, left side impact.

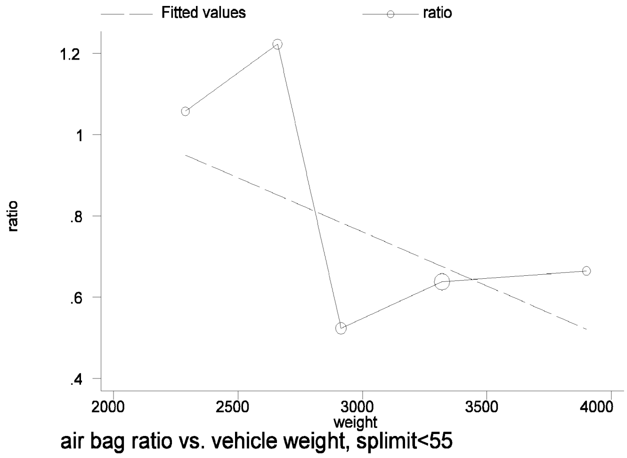


Figure 2.2.4-13 Ratio of driver fatality risks in cars with and without air bags, versus car weight, speed limit <55 mph. Single car crashes, left side impact.

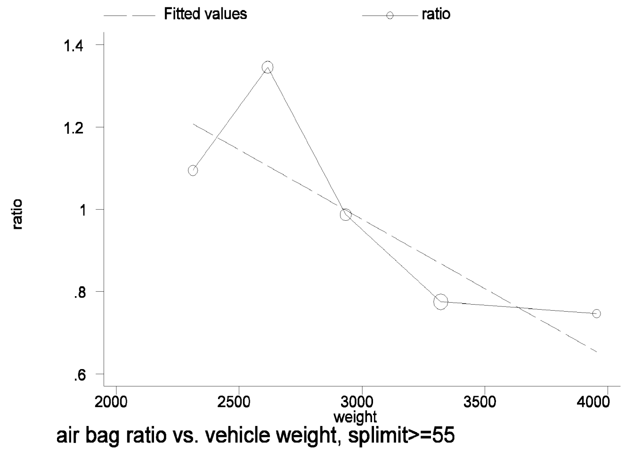


Figure 2.2.4-14 Ratio of driver fatality risks in cars with and without air bags, versus car weight, speed limit >= 55 mph. Single car crashes, left side impact.

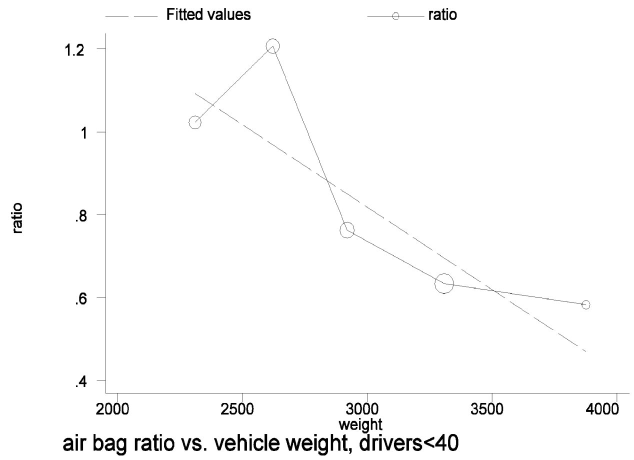


Figure 2.2.4-15 Ratio of driver fatality risks in cars with and without air bags, versus car weight, driver age < 40 years. Single car crashes, left side impact.

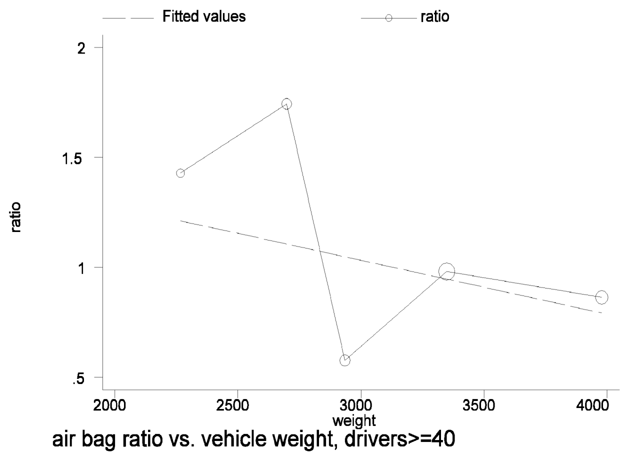


Figure 2.2.4-16 Ratio of driver fatality risks in cars with and without air bags, versus car weight, driver age >= 40 years. Single car crashes, left side impact.

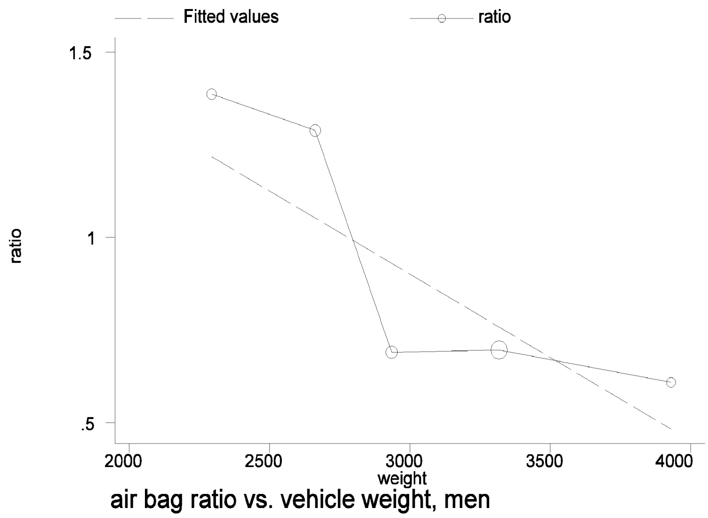


Figure 2.2.4-17 Ratio of driver fatality risks in cars with and without air bags, versus car weight, male driver. Single car crashes, left side impact.

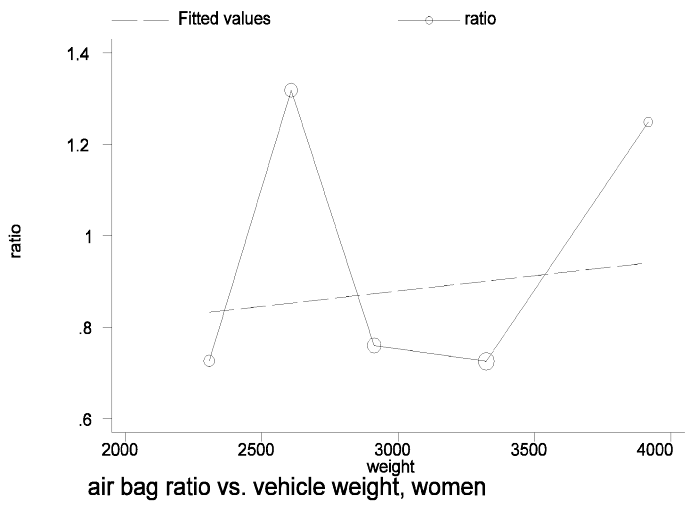


Figure 2.2.4-18 Ratio of driver fatality risks in cars with and without air bags, versus car weight, female driver. Single car crashes, left side impact.

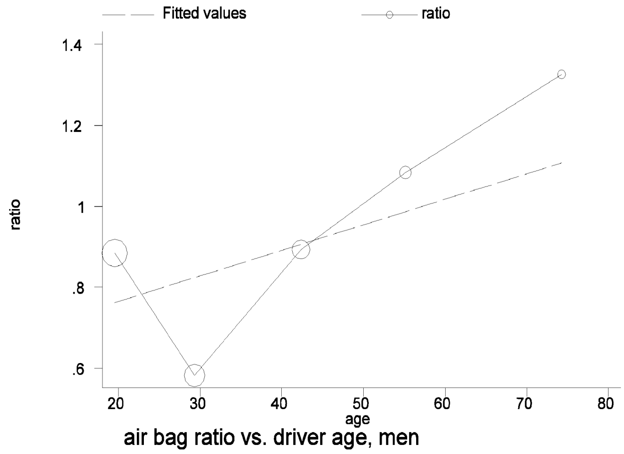


Figure 2.2.4-19 Ratio of driver fatality risks in cars with and without air bags, versus driver age, male drivers. Single car crashes, left side impact.

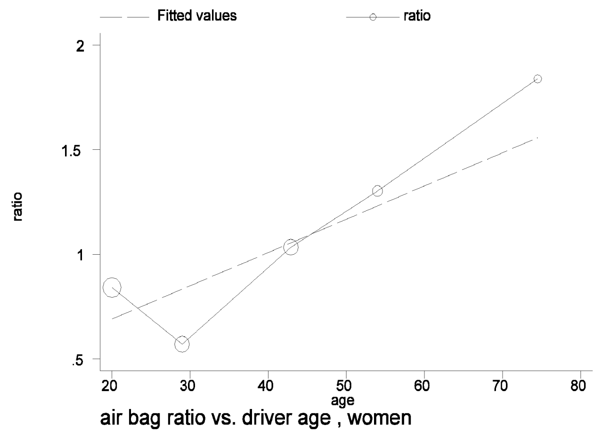


Figure 2.2.4-20 Ratio of driver fatality risks in cars with and without air bags, versus driver age, female drivers. Single car crashes, left side impact.

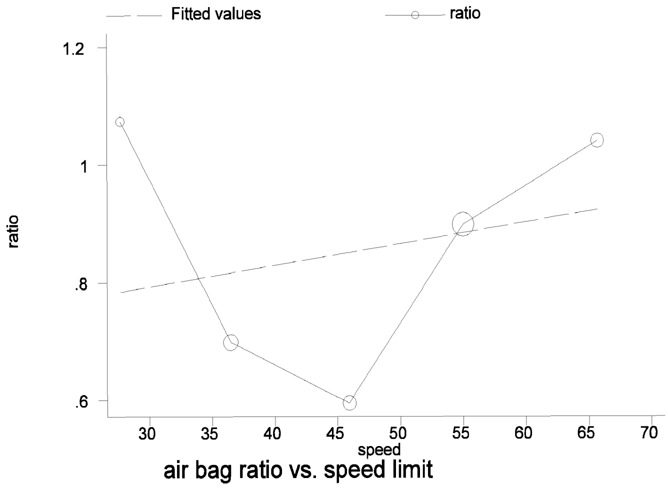


Figure 2.2.4-21 Ratio of driver fatality risks in cars with and without air bags, versus speed limit. Single car crashes, left side impact.

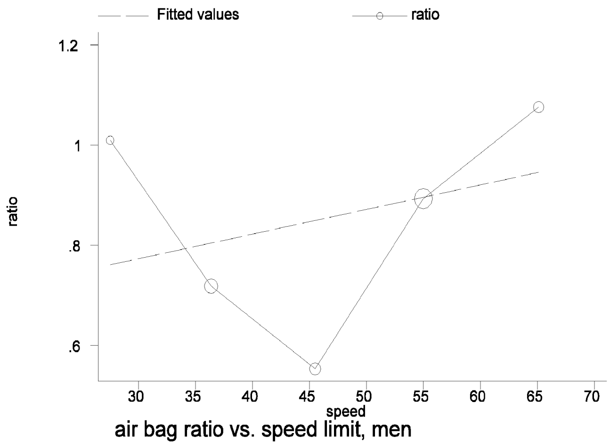


Figure 2.2.4-22 Ratio of driver fatality risks in cars with and without air bags, versus speed limit, male driver. Single car crashes, left side impact.

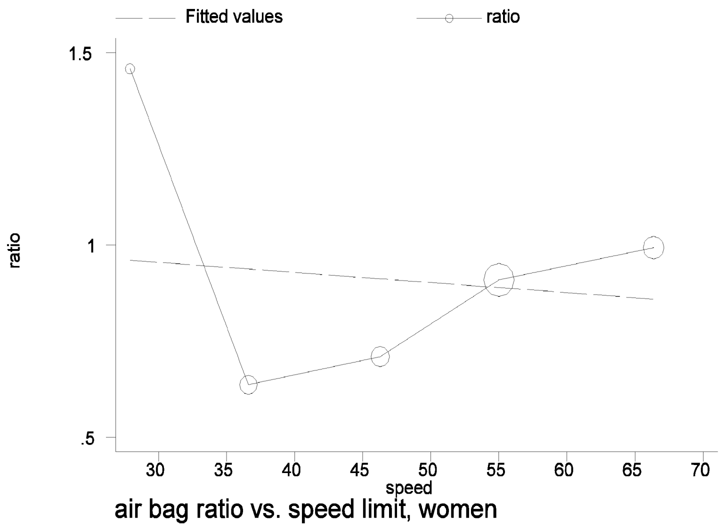
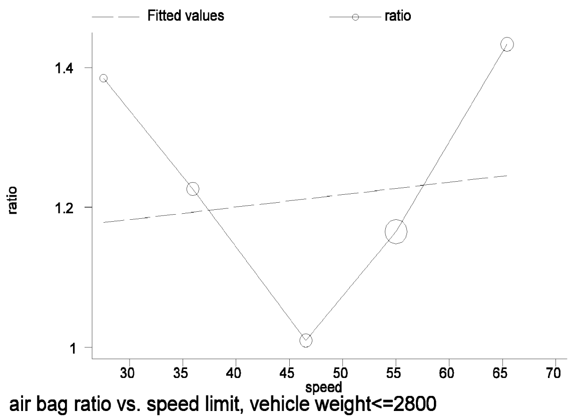
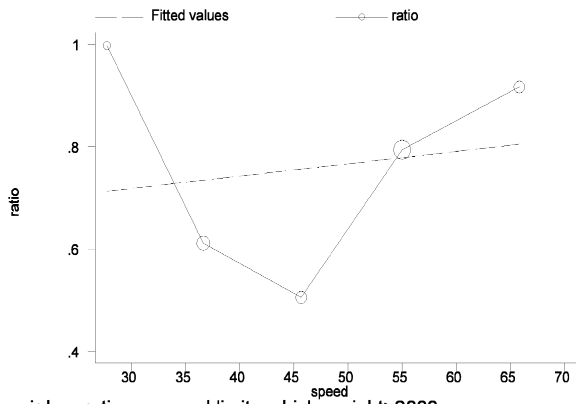


Figure 2.2.4-23 Ratio of driver fatality risks in cars with and without air bags, versus speed limit, female driver. Single car crashes, left side impact.



air bag ratio vs. speed limit, vehicle weight<=2800

Figure 2.2.4-24 Ratio of driver fatality risks in cars with and without air bags, versus speed limit, car weight <= 2,800 lb. Single car crashes, left side impact.



air bag ratio vs. speed limit, vehicle weight>2800

Figure 2.2.4-25 Ratio of driver fatality risks in cars with and without air bags, versus speed limit, car weight > 2,800 lb. Single car crashes, left side impact.

To explore these patterns quantitatively, for each air bag car death/predicted risk was used as dependent variable and regressed upon the categorical variables used in the model. The result is shown in Table 2.2.4-4. The two terms - aside from the constant which differs by less than its standard error from 0 - represent the two rightmost points in Figure 2.2.4-10 and 11: the pure weight term represents most of the cars with predicted risks between 15/1,000 and 20/1,000, the triple interaction term represents the point with higher predicted risks.

Table 2.2.4-4 Coefficients of model for air bag effect in single car crashes, left side impacts.

variable	coefficient	non-standard error
(3,000 < = weight < 3,400)	-.22	(.13)
(3,000 < = weight < 3,400) ∗ (25<=age<40) ∗ (35<=splimit<55)	-.59	(.12)
constant	.04	(.08)

Also calculated were effectiveness estimates for the subsets of the cases defined by low and high values of each model variables, one at a time (Table 2.2.4-5).

Table 2.2.4-5 Driver fatality risk reduction in cars with air bags relative to the model for cars without air bags, in percent. Single car crashes, left side impacts. E1 are estimates 1- (actual driver deaths)/(expected driver deaths), E2 are averages of (1-death/risk), calculated for each case. Non-standard error in parentheses.

subsets of cases	E1	E2
risk < 15/1,000	2 (14)	0 (15)
risk > = 15/1,000	48 (10)	36 (10)
men	20 (11)	5 (12)
women	15 (14)	4 (16)
age < 40	23 (10)	2 (14)
age > = 40	6 (14)	3 (14)
weight < = 2,800	-19 (17)	-16 (17)
weight > 2,800	29 (11)	13 (14)
splimit < 55	31 (12)	6 (15)
splimit > = 55	-3 (15)	-4 (16)

2.3 The effect of expanding the coverage of the United States

A potentially serious problem with the approach used is that VINs are nearly completely missing in a number of the PSUs used for collecting the GES data. VINs are missing in nearly all PSUs in the Northeast region of GES. Therefore, these PSUs were excluded from the GES data base, and the corresponding states were excluding from the FARS data base.

The situation is "cleanest" in the Southern GES region. Only in one of the 18 PSUs were most VINs missing. This PSU was excluded, and expansion factors for the 7 other PSUs in the same PSU stratum adjusted by a factor of 8/7, which is statistically valid. The GES data for these 17 PSUs were combined with the FARS data for the states in this region. They contain about half of the fatal crashes in the U.S.

Air bag effectiveness estimates were made for this region. Because the GES data were statistically valid adjusted, and the FARS data contain a large part of all fatal crashes, these estimates should be the most precise ones, and represent a large part of fatal crashes.

In the Central (also called Midwest) GES region, 4 out of 16 PSUs had missing VINs. Again, one can omit them and adjust the expansion factor for the remaining PSUs in a valid manner. However, because 1/4 of the PSUs are omitted, one can expect some loss of statistical precision. The second set of analyses was performed with the combined data from the South and Central regions.

In the West, VINs were missing in 4 out of 12 PSUs. In principle, one could have omitted these PSUs and adjusted the expansion factors for the remaining 8 ones. This would have been formally statistically valid. However, all 4 PSUs with missing VINs are in California which accounts for the majority of crashes in the Region. This would have resulted in an unacceptable bias. Therefore, the PSUs in California were excluded, and the FARS data from California also. The more complicated adjustments of the expansion factors for the remaining PSUs are described in Appendix A.

The combination of the FARS and GES data from the South, the Central region, and the West excluding California ("VINUS") was used for the majority of the analyses in this study. It contains nearly 80% of the traffic deaths in the U.S.

Table 2.3-1 shows various air bag effectiveness estimates in car-car collisions for the three combination of regions. They are not independent: "all" collisions include the other collision configurations, estimates for cars with air bags include cars with driver only air bag for which separate estimates are shown. There seem to be no systematic differences between the estimates for the three combinations of regions; the differences are always less than the non-standard errors of the estimates. There is, however, a clear pattern in these non-standard errors: those for the combination of South and Central tend to be noticeably smaller than those for the South alone. The error estimates for the VINUS tend to be only slightly lower than for the combination South and Central. On the average, adding the Central region reduces the non-standard error by 18% relative to those for the South alone, with a range of 4% to 32%.

Adding the West excluding California reduces the non-standard errors further by only 3%, with a range from a 8% reduction to an 18% increase.

Table 2.3-2 shows corresponding data for single car crashes. The overall pattern is very similar to that seen in 2.3-1, though the numerical values are very different. In this case adding the Central region reduces the error only by 10% below that for the South alone. The range is from a 28% decrease to a 13% increase.

Adding the West excluding California reduces the errors further by 4%, with a range from a 9% to an increase by 18%.

Overall, one can conclude that combining the South and Central regions gives about the same estimates as the South alone, but that the errors are noticeably decreased. Adding the West excluding California again does not seem to change these estimates systematically. However, the error estimates are only minimally improved.

Therefore, it appears adequate to use the combination of the Southern and Central regions for similar studies. Adding the West excluding California would add little to the statistical precision, though it would improve at least the appearance of greater national representativeness. A disadvantage is that to adjust the expansion factor for the Western PSUs one needs data which are not readily publicly available.

Table 2.3-1 Driver fatality risk reduction (percent) by air bags, in car-car collisions. Estimates based on only the Southern GES region, the South and Central regions, and the VINUS (the United States, excluding the Northeast and California). Non-standard errors are in parentheses.

collision configuration and type of estimate	South	South and Central	VINUS
all collisions, all cars with air bags			
overall reduction	44 (6.9)	42 (5.7)	42 (5.4)
average of reductions	43 (7.9)	42 (6.7)	41 (6.4)
cars with driver air bag only			
overall reduction	35 (7.8)	34 (6.2)	34 (5.9)
average of reductions	31 (10.3)	36 (7.9)	35 (7.5)
frontal impacts			
all cars with air bags			
overall reduction	48 (6.3)	47 (5.3)	45 (5.2)
average of reductions	53 (7.1)	54 (6.0)	52 (6.1)
cars with driver air bag only			
overall reduction	42 (7.1)	40 (5.7)	40 (5.4)
average of reductions	45 (8.3)	47 (6.6)	45 (6.4)
right side impacts by front			
all cars with air bags			
overall reduction	27 (9.4)	26 (7.1)	29 (6.7)
average of reductions	38 (11.2)	46 (8.9)	39 (10.5)
cars with driver air bag only			
overall reduction	19 (14.3)	22 (9.8)	26 (9.0)
average of reductions	31 (15.4)	32 (14.8)	37 (14.8)
left side impacted by front			
all cars with air bags			
overall reduction	26 (12.3)	24 (9.4)	19 (9.4)
average of reductions	22 (10.1)	19 (9.3)	19 (8.9)
cars with driver air bag only			
overall reduction	16 (14.0)	15 (11.1)	13 (10.3)
average of reduction	8 (14.3)	12 (12.2)	13 (11.2)

Table 2.3-2 Driver fatality risk reduction (percent) by air bags, in single car crashes. Estimates based on only the Southern GES region, the South and Central regions, and the VINUS (the United States, excluding the Northeast and California). Non-standard errors are in parentheses.

impact car and type of estimate	South		South and Central		VINUS	
all crashes						
all cars with air bag						
overall reduction	30	(8.5)	33	(8.1)	33	(7.5)
average of reductions	28	(9.2)	32	(8.2)	32	(7.7)
cars with driver air bag only						
overall reduction	29	(9.5)	33	(7.7)	32	(7.7)
average of reductions	28	(10.0)	32	(7.9)	32	(7.5)
frontal impacts						
all cars with air bags						
overall reduction	39	(7.6)	42	(7.0)	44	(6.4)
average of reductions	35	(8.5)	41	(6.9)	42	(6.4)
cars with driver air bag only						
overall reduction	40	(9.1)	41	(7.1)	42	(6.7)
average of reductions	34	(9.9)	39	(7.1)	39	(6.9)
right side impacts						
all cars with air bags						
overall reduction	16	(11.5)	14	(12.8)	11	(12.2)
average of reductions	5	(14.9)	-4	(16.9)	8	(16.7)
cars with driver air bag only						
overall reduction	14	(13.0)	14	(12.2)	13	(11.7)
average of reductions	10	(15.1)	5	(14.2)	3	(14.1)
left side impacts						
all cars with air bags						
overall reduction	23	(11.4)	18	(11.0)	19	(10.5)
average of reductions	0	(13.9)	3	(14.5)	5	(13.5)
cars with driver air bags only						
overall reduction	26	(16.3)	20	(13.9)	20	(13.5)
average of reduction	5	(19.2)	10	(15.6)	9	(15.0)

3. Conclusions and recommendations

3.1 Combining FARS and GES files

Fatality, and more often injury risks per crash involvement have traditionally been studied by using a state's accident data file which contains all reported accidents. Treating killed (or injured) or survived (or not injured) as a discrete dependent 0/1 variable allows to model fatality or injury risks as functions of various crash and pre-crash factors.

The number of fatalities in even the largest states is relatively small. Therefore, no "fine grained" studies are possible. Only the FARS files contain a sufficient number of fatal crashes to allow detailed e.g. at the make/model level, studies. However, FARS contains no non-fatal crashes; therefore, one can not calculate absolute, but only certain relative fatality risks. For detailed analyses, further assumptions are necessary. The only database covering like FARS the entire US and containing non-fatal accidents are the GES files (aside from the CDS files which contain only very few cases). GES is a sample of all police reported crashes; therefore, each case has a weight or expansion factor, indicating how many actual crashes it statistically represents.

In principle, it is possible to combine these two files, giving the FARS cases an expansion factor 1, and dropping the fatal crashes from the GES files. Assigning a 0/1 variable - survival or death - to each person involved in a crash allows modelling fatality risks.

This is conceptually straightforward, but there are a number of technical difficulties. First there is a subtle conceptual problem. FARS is for all practical purposes a complete census of all fatal crashes in the US, but GES is not a sample from all crashes, but from all police reported crashes. Legal requirements for reporting accidents, and also actual practices differ among the states (and sometimes even within states). This creates no problems if GES is used for generating descriptive estimates of crash numbers - for which purpose it was designed. However, if one uses GES data to estimate fatality risks, the following effect can arise: a state with a higher reporting threshold will have fewer non-fatal crashes than a state with a lower reporting threshold, even if the fatal crash numbers were the same. Therefore, fatality risks per crash would appear higher in the first state than in the second one. If the states differed in some crash or pre-crash factors, such as the age distribution of drivers, the distribution of speed limits, etc., these estimates of the effects of such factors can be confounded by the effects of reporting differences. Such effects are in any case difficult to determine. In this case, it is even more so because the GES sample is not designed to provide estimates by state. In this study, we did not address this question.

Most data elements in FARS and GES are the same or very similar, and the codes for each element are also the same or similar. However, there are a few exceptions. Crash severity differs greatly between urban and rural environments, and inclusion of the categorical urban/rural variable in analyses can avoid or reduce potential spurious effects. FARS provides such a simple variable, GES does not. In this study, we avoided this difficulty by using the speed limit as one of the variables, because the urban/rural differences in crash severity is probably due to differences in travel speed. Both FARS and GES contain the speed limit, though in GES files it is often missing. Our models showed that using the speed limit was probably even better than distinguishing only urban and rural, because the fatality risk appeared to be a smooth function of the speed limit over a wide range.

Another data item where FARS and GES are not fully compatible is the impact point on the vehicle. FARS uses a 1-12 code, corresponding to a clock face, whereas GES distinguishes only the four sides and the four corners of the vehicle. By aggregating some FARS codes, one can roughly match the two data sets. This might not be a great loss, because the FARS codes may not be as precise as they appear: they are based on the differing codes on the states' accident report forms which do not seem to be unambiguously translatable into the FARS code.

When studying fatality risks, safety belt use is of interest, be it as of primary interest or as a confounding factor. In FARS, belt use for killed vehicle occupants may by fairly reliably known because police tend to pay more attention to them. For less severely injured, and especially for uninjured occupants it is probably much less reliable. In GES, reported belt use, especially for uninjured occupants must be considered unreliable. These problems, however, are not specific to the combination of FARS and GES data. They occur similarly if one uses states' data. Therefore, we did not use belt use in our modelling.

To obtain reliable information on the presence of air bags, the VIN was used. FARS contains the VIN for practically all cars. In GES, VIN are systematically missing. Simply dropping the cases without VIN could have introduced biases which to estimate would have required very extensive work.

The missing VIN followed a simple pattern: either nearly all cars in a PSU had a VIN, or nearly none. Therefore, a statistically rigorous approach was possible. First, all PSUs with missing VIN were dropped, then adjustments were made. Since in nearly all PSUs in the northwestern GES regions VIN were missing, the entire region was omitted. Also, the FARS data for the states constituting this region were omitted. Because these omitted cases were exactly matched, the file remained statistically valid, though no longer nationally representative; however, if one wants to estimate physical or physiological relations (relating to the risk of dying) this is not a critical aspect.

In the Southern and Central regions, only a few PSUs were missing. This could be handled by retaining all FARS data for the states constituting these regions, and by adjusting the expansion factor for the GES cases in the PSUs which were retained. This is statistically valid.

In the Western region, the same approach could have been used, and would also have been statistically valid. However, all missing PSUs were in the state of California, which provides the majority of cases in the western region. This raised the concern that making estimates for the entire western region, including California, based on GES data from only states other than California, could introduce biases. Therefore, we defined a truncated western region which excluded California.

Then, we dropped the FARS data from California, and the GES data from the PSUs in California. NHTSA provided the necessary data so that the expansion factors for the remaining PSUs could be adjusted so that they provided estimates for the western region excluding California. This resulted in a statistically valid data file for the Western region excluding California ("W x CA").

All analyses were performed with the files thus created, which contained a statistically valid representation of the US, excluding the Northeast and California ("VINUS") This exclusion could introduce biases in the results, but since the Northeast and California have only about 20 percent of the fatal crashes in the US, this bias should not be great.

We conclude that it is possible to study relations between car occupant fatality risks and pre-crash factors identifiable by the VIN (also including some other factors) by combining FARS and GES data.

It might also be possible to modify this approach for other studies, where missing key variables show a pattern different from that of missing VINS.

3.2 Estimates of air bag effectiveness

Tables 3.2-1 and 2 summarize the air bag effectiveness estimates made in chapter 2. In collisions between two cars, the effect is greatest in frontal impacts, as one would expect. Surprising is that there are also effects - “significant” by conventional standards - in side impacts, though much smaller than in frontal impacts. The effect in all impacts combined is, somewhat surprising, not much smaller than that in frontal impacts. The pattern is very similar for cars with driver-only air bags - which are of earlier model years and therefore on the average older than cars with dual air bags - however, the effects are slightly smaller. That may be due to improvements of the air bags in more recent model years, but it could also be the result of more subtle effects: cars with dual air bags being younger in our data base, and being more often involved in crashes in the later calender years. User characteristics and uses are correlated with car age, and possibly with calender year.

Table 3.2-1 Estimates of reductions (in percent) of driver deaths in cars with air bags compared with cars without air bags. Collisions between two cars, and single car crashes when rollover was not the first harmful event. Non-standard errors are in parentheses.

impact	collisions	single car crashes
all	42 (5)	33 (8)
front	45 (5)	44 (6)
right side	29 (7)	11 (12)
left side	19 (9)	19 (11)
	cars with driver-only air bags	
all	34 (6)	32 (8)
front	40 (5)	42 (7)
right side	26 (9)	13 (12)
left side	13 (10)	20 (14)

Table 3.2-2 Estimates of the average driver fatality risk reduction in cars with air bags compared with cars without air bags. Collisions between two cars, and single car crashes where rollover was not the first harmful event. Non-standard errors are in parentheses.

impact	collisions	single car crashes
all	41 (6)	32 (8)
front	52 (6)	42 (6)
right side	39 (10)	8 (17)
left side	19 (9)	5 (14)
	cars with driver-only air bags	
all	35 (8)	32 (8)
front	45 (6)	39 (7)
right side	37 (15)	3 (12)
left side	13 (11)	9 (15)

For single car crashes, the patterns are similar to those for collisions between cars. In frontal impacts, the effects are very close to those in collisions, but in side impacts, they are much smaller and have much larger non-standard errors - indeed, they would not be "significant" by conventional criteria.

That air bags have effects in side impacts in collisions with another car, but a much smaller, if any effect in side impacts in single car crashes is not implausible. A car struck in the side by another car will usually be deflected and decelerated, the air bag may deploy and prevent the driver from hitting the forward interior of his car. In single car crashes, a side impact may more often involve sideways sliding into an object, so that the car will not be decelerated in the forward direction; the air bag is less likely to deploy, and if it deploys it may offer less protection to the driver who is more likely to hit the door than the forward part of the occupant compartment.

The average risk reductions for all impacts, Table 3.2-2, are practically the same as the reductions of driver deaths. In collisions, however, the average risk reductions in frontal and in right side impacts are much - though not "significantly"- larger than the reductions of total deaths; for left side impacts they are equal. In single car crashes, the average risk reduction and the reduction of total deaths are about equal; for side impacts the differences are opposite to those for collisions: the average risk reduction is smaller than the reduction of deaths.

A simplified conclusion is that air bags reduce driver fatality risks and deaths by between 40 and 50% in frontal impacts with cars or objects. There is also a strong indication that they have an effect of between 30 and 40% in collisions with another car impacting the right side. They may also have an effect in left side impacts in collisions with other cars. It appears less likely, but should not be excluded that they also have a small effect in side impacts in single car crashes.

The findings about effects in side impacts suggest that effectiveness estimates which rely on the assumption of no effect in side impacts need to be further examined before they can be accepted; they may underestimate the effect of air bags.

The magnitude of the effects found is surprising, because they are effects above those provided by safety belts as used. During the period covered by the data base, safety belt use increased.

What could explain the surprisingly large effect of air bags? The data covers a transition period where only few cars of a model year had air bags, but at the end al new cars had air bags. During the transition period, buyers could choose between cars with and without air bags. If risk averse drivers who even without air bags were less likely to get into severe accidents had preferentially bought cars with air bags, then the estimated air bag effect would have been exaggerated.

Another possibility is that drivers who did not use safety belts bought air bags as "passive protection" - as which air bags were initially advertised by their protagonists. Then, the pure air bag effect, and not the additional effect above that of safety belts would have been estimated. Drivers to which this applies are less likely to be risk averse; so this group is likely to be different from that discussed in the preceding paragraph.

There is also the possibility of a reporting effect. The denominator in our risk estimates are police reported accidents. The reporting of an accident depends on various factors. The legal requirements differ among the states, and actual reporting practices even within states. Typically, all accidents involving an injury are reportable. In collisions between vehicles, usually at least one driver has an interest to report the accident, to have it documented for insurance purposes, even if it involves only property damage. In larger cities, however, the police may not be required to investigate and report property damage only accidents. In single car crashes with property damage only, the driver usually has no incentive to report an accident. While air bags reduce this severity of major injuries and reduce the fatality risk in a crash, they also cause minor injuries which would not have had occurred without the air bags. This can have the effect of increasing the number of crashes involving cars with air bags which are reported to the police. This would result in a reduction of the estimated fatality risk, even if there were none, or an overestimate of an actual reduction of the fatality risk.

Air bag effects may depend not only on the crash configuration, but also on other factors. This was also explored in chapter 2. Table 3.2-3 summarizes the resulting models. The constant term can be interpreted as "baseline" effect of air bags, to be modified by the other terms included in the models.

Table 3.2-3 Coefficients of regression models for drivers fatality risk reductions by air bags, by crash configuration. A negative sign indicates a beneficial effect. Non-standard errors in parentheses.

impacts:	all	front	right	left
		collisions between two cars		
constant	-.31 (.08)	-.44 (.05)	-.38 (.07)	-.20 (.10)
female	-.16 (.07)	-.19 (.03)		
female ∗ log(weight/2,800)	-.45 (.15)			-1.27 (.51)
female ∗ (age-30)/10		.07 (.03)		.09 (.03)
		single car crashes		
constant	-.23 (.08)	-.30 (.07)	.01 (.14)	.04 (.03)
female	-.18 (.05)	-.12 (.05)		
female ∗ log(weight/2,800)			4.24 (1.98)	
(age -30) ∗ male	-.05 (.02)	-.10 (.04)		
(age -40) ∗ (age >40) ∗ male		.14 (.05)		
log(weight/2,700) ∗ (weight <2,700)		.68 (.24)		
log(weight/2,700) ∗ (weight ≥2,700)		-.51 (.16)		
(3,000 < =weight<3,400)				-.22 (.13)
(3,000 < =weight <3,400) ∗ (25 < =age <40) ∗ (35 < =splimit <55)				-.59 (.12)

In many cases, the factor “female” appears, alone or in interaction with vehicle weight or driver age. When it appears, the air bag effect is greater by 12 to 19 percentage points. When an interaction term between female and driver age appears, it has a positive sign, indicating that the air bag effect decreases with age for women. Its interaction with car weight appears in left side impacts in collisions with a very large negative coefficient. It would mean an effect of 65% for a 30 year old woman in a 4,000 lb car, but of - 23% in a 2,000 lb car! For a male driver, it would always be 20%. Another interaction with car weight appears for right side impacts in single car crashes. Here it has a positive sign, with the result that the air bag would increase the risk for a woman driving a 4,000 lb car by 360%, and reduce it for a woman in a 2,000 lb car to below 0! Despite of the “significance” of this term by conventional criteria, it does not make physical sense.

In single car crashes with front impacts, interactions between male and driver age appear: an increase of air bag effects up to 40 years, a decrease thereafter. In all single car crash configurations combined, only a weaker effect increasing with age remains.

In single car crashes with frontal impacts, two weight terms appear. They result, e.g. for a 30 year old male driver, in an air bag effect of 50% in a 2,000 lb car, 30% in a 2,700 lb car, and again 50% in a 4,000 lb car. This is not very plausible.

In the model for left impacts in single car crashes, the triple interaction term between car weight, driver age, and speed limit appears with a very high conventional “significance” level; there is also a much weaker simpler categorical weight term. This triple interaction term appeared also in the risk model for cars without air bags (Table 2.2.4-2), and it applied only to few cases. From a practical point of view, the weaker term for cars between 3,000 and 3,400 lb is more important because it applies to a much larger number of cases.

In sum, the exploratory analyses of air bag effects in relation to pre-crash factors showed no convincing relations; only a suggestion that air bags might have greater effects for women.

Because we noticed already in chapter 2 that the results of these regression analyses were of doubtful validity, we also took a more simplistic look at the data. Accidents were split in various ways into two groups: male and female drivers, low and high driver age, low and high car weight, and low and high speed limits. For each of these groups, air bag effects were estimated. The results are summarized in Table 3.2-4.

The data in this table are not directly comparable with those in Table 3.2-3: while the models presented in Table 3.2-3 attempted to separate the effect of the various factors, this is not the case in Table 3.2-4 which only shows potentially confounded effects. For instance, apparent differences between the low and high driver age group might, at least partially, be due to the use of heavier car by older drivers, and the same effect would affect apparent differences between lighter and heavier cars. Similarly, driver sex and car weight may be confounding factors.

For collisions between two cars, there are no differences in the overall effects between men and women, old and young drivers, and low and high speed limits. Only for car weights a difference is suggested: the air bag effect appear to be greater for heavier cars, but the difference would not be "significant" by conventional standards.

Table 3.2-4. Estimates of air bag effectiveness by crash configuration and pre-crash factors. The estimates are made for two different levels of each factor. Non-standard errors are in parentheses.

	collisions				single car crashes	
impacts	all	front	right	left	right	left
crash factor						
		overall reductions of driver deaths				
men	40 (6)	45 (6)	27 (9)	20 (12)	13 (12)	20 (11)
women	43 (6)	45 (6)	31 (7)	16 (10)	1 (20)	15 (14)
< 40 years	41 (7)	45 (7)	10 (11)	12 (9)*	15 (12)	23 (10)
> =40 years	43 (5)	46 (5)	40 (9)	23 (13)*	1 (20)	6 (14)
< =2,800 lb	37 (6)	41 (7)	10 (15)	17 (14)	24 (14)	-19 (17)
> 2,800 lb	44 (5)	48 (5)	37 (7)	19 (10)	4 (14)	29 (11)
< 55 mph	42 (7)	51 (7)	39 (9)	21 (12)	6 (15)	31 (12)
> =55mph	41 (7)	42 (7)	19 (12)	16 (15)	16 (15)	-3 (15)
		average reductions of fatality risks				
men	31 (7)	44 (7)	30 (9)	3 (10)	12 (13)	5 (12)
women	49 (6)	59 (8)	43 (13)	29(10)	-30 (28)	4 (16)
< 40 years	37 (7)	56 (8)	23 (16)	23 (10)*	-2 (18)	2 (14)
> =40 years	47 (6)	46 (8)	54 (13)	-5 (16)*	-26 (22)	3 (14)
< =2,800 lb	41 (7)	52 (8)	30 (19)	16 (14)	20 (15)	-16 (17)
> 2,800 lb	41 (6)	52 (7)	59 (9)	19 (10)	-22 (20)	13 (14)
< 55 mph	41 (7)	53 (8)	39 (10)	19 (10)	-6 (19)	6 (15)
> =55 mph	41 (7)	45 (7)	18 (11)	6 (15)	-11 (21)	-4 (16)

*In these cases, the breakpoint is 60 years.

For the average risk reductions, the pattern is different: air bag effectiveness differs greatly between men and women; it approaches conventional “significant”. That this greater reduction in risk does not result in a greater reduction of deaths probably resulted from women tending to have less severe accidents where the risk reduction saves fewer lives than in the more severe accidents men get involved in.

There is also a difference between young and old drivers (but it is reverse if one looks at frontal impacts only), but none between light and heavy cars, or low and high speed limits. None of the other crash configuration shows a clear pattern.

In sum, all Table 3.2-4 does is to support the tentative conclusion from Table 3.2-3, that air bag effectiveness may be greater for women than for men.

3.3 Comparison with Kahane's estimates

The most thorough air bag effectiveness estimates have been made by Kahane[1]. The scope of his work differs in many respects from that in this study. Therefore, only limited comparisons are possible.

The data bases are different. Kahane uses only FARS data from the calender years 1986 through 1996, whereas this study uses FARS and GES data for the calender years 1991 through 1999, and excludes data from certain states. The differences in time frames should have little, if any effect on the results, except that this study includes also cars of more recent vintage.

The selection of crashes differs between the studies. Kahane used all crash involved cars. The present study always separated single car crashes and collisions. Since air bags are not designed to deploy in rollovers, and may have little or no effect even if they deploy, single vehicle crashes where a rollover was the first harmful event were excluded from this study. Therefore, our estimates of air bag effectiveness in single vehicle crashes should be higher than Kahane's.

Kahane uses all cars in collisions. In this study, only cars in collisions with another car were used, because only such collisions could be adequately modelled with acceptable effort. The effect of this selection is not obvious. However, since this study excluded collisions with trucks, including large trucks, where air bags may have less, if any effect, one may expect that this selection results in higher estimates of effectiveness than Kahane's more comprehensive selection.

Kahane uses two approaches. One uses only vehicles in fatal crashes which have a driver and a right-front-seat occupant. He compares the ratios of drivers to right-front-seat occupant deaths in cars with, and without driver side air bags.

The other approach relies on the assumption that air bags have an effect only in frontal impacts. Comparing the ratios of deaths in frontal to those in non-frontal impacts between cars with and without air bags also gives an estimate of air bag effectiveness.

Kahane controls the comparisons only for one factor: vehicle make. In a few cases, air bag and non-air bag cars were available in the same model years.

In most cases, the non-air bag cars are earlier model years than those with air bags. The average differences range from 0 to 4 years, and are most frequently 2 or 2.5 years (obtained from Kahane's Table 1.1). Certain factors are related to vehicle age,

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[1]Fatality Reduction by Air Bags. Analyses of Accident Data Through Early 1996. NHTSA report DOT HS 808470, August 1996.

e.g. driver sex: women tend to drive slightly older cars than men. Therefore, the non-air bag cars in Kahane's data base should have a higher proportion of women drivers. Since women have lower fatality risks than men, this would bias the airbag effectiveness estimates to the low side.

In this study, an attempt was made to control for confounding factors by using empirical mathematical models for the fatality risk. Though the models represent the data overall quite well, some unexplained discrepancies in relation to the factors used for modelling remain. More important is that the models rely critically on GES data. It is known that the completeness of reporting non-injury accidents differ among the states. There is also some doubt how completely non-injury single vehicle accidents are reported - drivers have no incentive to do so, contrary to the situation in collisions. Changes in injury risk - as distinct from fatality risk - may confound the reporting. Kahane's relying on only FARS data avoids this potential problem.

Kahane's other approach relies essentially on the assumption that air bags have no effect in non-frontal impacts. In this study, we found potential effects in left and right side impacts in collisions, and also large, though less certain effects in single car crashes. Tabulation of the variable air bag deployment - which is very incomplete - in the FARS file showed that many deployments occurred in side impacts. Therefore, one can expect that Kahane's effectiveness estimates are on the conservative side, compared with this study.

Table 3.3-1 shows an attempt to compare Kahane's estimates of car air bag effectiveness in collisions (his Table 2-9) with those of this study. The column "absolute effect" reproduces the overall reduction estimates based on the VINUS data, for all cars with air bags. The next column "effect relative to right impact" shows the air bag effect in all impacts, and in frontal impacts relative to that in right side impacts. The number 18, e.g. is calculated by (1-0.42)/(1-0.29) = 1-0.18. The corresponding holds for the column "effect relative to left impact".

These two columns should be very roughly comparable to the last column which shows Kahane's estimates based on comparing deaths in frontal with other impacts. However, it is not strictly comparable because Kahane's comparison group is much broader than just left and right sides impacted by the front of the other car. The second to last column shows Kahane's estimates based on comparing drivers and right-front-seat passengers. It should be roughly comparable to the "absolute" estimates in the first column.

Table 3.3-1 Comparison of air bag effectiveness estimates in collisions. For explanation of the columns and interpretation see the text.

impacts	this study			Kahane	
	absolute effect	effect relative to		comparison	
		right impact	left impact	driver/ passenger	front/ other
all	42	18	28	14	12
front	45	23	32	39	26
right	29				
left	19				

Table 3.3-2 Comparison of air bag effectiveness estimates in single car crashes. For the explanation of the columns and interpretation see the text.

impacts	this study			Kahane	
	absolute effect	effect relative to		comparison	
		right impact	left impact	driver/ passenger	front/ other
all	33	25	17	4	12
front	44	37	31	22	26
right	11				
left	19				

Kahane's estimate of 14% is much lower than the 42% estimated by this study. This is not too surprising since Kahane includes collisions with all trucks which also includes such severe ones that air bags have little effect. His alternative estimate of 12% is also lower than the 18% and 28% obtained in this study.

For frontal impacts, the estimates agree much better. Our 45% is not too far from Kahane's 39%, and Kahane's estimate of 26% is between our estimates of 23 and 32%.

Table 3.3-2 shows the corresponding comparisons for single vehicle crashes. For all impacts, the pattern is similar to that in Table 3.3-1: 4% is much less than 33% and 12% is much less than 17% and 25%. For frontal impacts, Kahane's 22% is only half of our estimate of 44%, and his relative estimate of 26% is below 37% as well as 31%.

If our estimates were consistently higher than Kahane's, one could speculate that this is due to the narrower selection of crashes used in the study. Such a hypothesis could be relatively easily checked. However, the pattern is not that simple, and considerable work may be needed to find an explanation.

3.4 Recommendations concerning FARS and GES

In this work, FARS and GES data were combined to study a car characteristic: the availability of air bags. To identify cars by make, model, and model year, and possibly additional characteristics, the VIN is needed. FARS has nearly complete VINs, but in GES VINs are systematically missing. We could avoid the resulting difficulties by excluding the Northeast and California from all data bases. This could possibly create some biases.

To avoid such potential biases and simplify the study of the effects of which characteristics, it would be desirable to have the VIN for as many GES cases as possible. For instance, it could be obtained when coding the GES cases via the vehicle license number from motor vehicle registration files.

Safety belt use is an important factor influencing injury and fatality risks, and should be accounted for when studying injury or fatality risks. Often information on safety belt use in police accident reports is based on statements by the parties involved and therefore unreliable. However, in fatal accidents the police may look for physical evidence of belt use and describe it in the narrative of the accident. An additional data field indicating the reliability of safety belt information in FARS, and possibly also in GES cases would be useful.

In most cases, the codes for data elements in FARS and GES agree. However, there are a few exceptions. For instance the urban/rural distinction, and the codes for impact on the vehicle. One should consider making these codes compatible.

The FARS impact codes and the GES impact codes are derived from a variety of different state coding formats. This translation is not always unambiguous. One should explore the possibility of adding a data field to the FARS and GES files, or creating supplementary files which provide the original codes.

Extend the scope of the FARS and GES Analytic User's Manuals by adding Appendices or Supplements. For GES, a detailed description of the sampling plan, and its changes over time, including changes of the components of the expansion factors would be very useful for in-depth analyses.

For both the FARS and GES manuals, simple tabulations of the frequency of "missing" and "unknown" codes by state for FARS, and by PSU for GES would be useful. This may be restricted to those data elements where the number of missing or unknown codes are not negligible.

If the original state codes differ from those used in FARS and GES, translation tables can be useful.

3.5 Recommendations on estimating air bag effectiveness

By now, estimating overall air bag effectiveness is of little practical importance. However, to estimate how it differs among crash types, and how it is influenced by pre-crash factor is still important to provide guidance for the further development of air bags. Such studies require as precise results as possible.

The present work used an approach which is conceptually valid. It calculated driver fatality risks, conditional upon a crash with certain pre-crash factors having occurred. It's only weaknesses are of a practical nature: it depends critically on the assumption that the reporting of non-fatal crashes is not influenced by the presence or absence of air bags.

Other approaches do not use information on non-fatal crashes and are therefore not subject to reporting biases. No explicit assumptions are required if one studies collisions between two cars in which at least one driver is killed. However, the results are limited to collisions, only relative risks are obtained, and the mathematical modelling of relative risks is more difficult. Another approach requiring no explicit assumption is to compare driver and right-front seat occupant in cars with none, one, and two air bags, where at least one of the front seat occupants is killed. Because there are complex empirical correlations between the ages, and the sexes of the two occupants, the analysis has to control for these factors, which is not simple. Again, only relative risks are obtained, and the results are limited to cars with two front seat occupants. Crashes involving cars with two front seat occupants are likely to differ from those with only one front seat occupant, at least because car occupancy differs between urban and rural environments.

Nevertheless, we do recommend that future studies also use all three of these approaches, applying them to exactly matched data bases. That way it may be possible to identify the influence of the weaknesses of each approach, and to obtain the most reliable and comprehensive estimates possible.

There are two other approaches which we do not recommend. Both use only cases where a driver (or a right-front seat occupant, if the effects of passenger air bags are studied) is killed. The first uses the assumption that air bags have no effects in side impacts (or, perhaps, even in all non-frontal impacts). This study has shown that this assumption is probably not true for collisions between two cars, though it might be true for single car crashes. The other uses fatal crash involvements as numerator, and registered vehicles as denominator, to calculate fatality risks per registered vehicle year. The latter can, in practice, be disaggregated only by make/model/model year, though in principle it could be disaggregated by any factor decodeable from the VIN. Such rates combine the crash risk per registered vehicle year and the fatality risk per crash involvement. Annual vehicle miles of travel decrease with vehicle age, and differ between vehicle classes and are not available at the necessary level of detail. Therefore one can not control for quantitative differences in use between cars with and without air bags. Neither can there be controls for factors such as driver age, driver sex, driving environment, and crash configuration. Therefore, this approach can at best give very crude, and at worst, very biased estimates.

It appears worthwhile to explore using CDS data together with FARS and GES data. The CDS data base is small, which results in large sampling errors, but the data collected are very reliable. Therefore, it might be possible to determine certain relations with a high accuracy, and use them in the analysis of FARS and GES data.

3.6 Recommendations on statistical work

This study used an inhomogeneous data base: a combination of FARS and GES. It depended critically on developing a mathematical model for the probability of death as a function of several variables. Making "point" estimates of the coefficients of such models poses no serious problems. Estimating errors of the estimated coefficients is not only practically, but also conceptually difficult. For such modelling, one has to assume that the numbers of FARS cases, and the numbers of actual cases from which GES is sampled are random variables, usually with a Poisson, perhaps with a negative binomial distribution. In addition, there are the sampling errors of GES.

It is desirable to have techniques that allow to handle this in a routine manner.

It is also desirable that they allow to separate the effects of the random variability of the crash counts, and the sampling variability due to the sampling of the GES cases, from the sampling errors resulting from the selection of the PSUs and PJs in GES. Since the selection of PSUs has remained constant over a long time, and PJs are also selected for longer time periods, these error components are approximately constant over time. Thus, they should be ignored in year-to-year comparisons, or trend analyses over short time periods.

The relations between fatality risk, car weight, and driver age are highly nonlinear. Most vehicle weights fall into a fairly narrow range, whereas the major changes of risk with weight occur outside of this range. Similarly, the number of cases is decreasing with increasing driver age, but the risk is dramatically increasing at the highest ages. Standard estimating procedures give greatest weight to the ranges with most cases, even though a practically negligible worsening of the fit in this range may allow a dramatically better fit outside it. It would be desirable to have simple procedures which allow to make such trade-offs.

To represent the highly nonlinear relations we found, we used "kinky" relations, including terms of the form $(x - a) * (x > a)$. Standard routines calculate errors for the coefficients of such terms, but it is not clear how they should be tested, because they are largely, possibly entirely, based on only part of the cases - sometimes a small part. This should be studied.

Some "errors" are correlated. For instance, a certain make/model may differ in crashworthiness from others of comparable weights. Thus, an error component by make-model should be considered. This could be done by adding a term for each make-model, but then it would no longer be possible to estimate a relation with car weight, except in a second level analysis of the "error" terms. A strategy to deal with this issue is needed.

“Influential observations” are of interest, especially at very low or high vehicle weights, or high driver ages, where there are only few cases. Techniques to deal with individual observations are available. In our context, however, situations arose where certain make/models, or a PSU constituted “influential groups”. Techniques to identify such groups are desirable.

Appendix A. Data

The data base were the 1991-99 FARS and GES files. The Volpe National Transportation Systems Center (VNTSC) prepared special files for this work. Two types of files were generated: single vehicle, non-rollover crashes, and collisions between two vehicles.

The single vehicle file included cases involving only one vehicle, car or LTV, not towing a trailer, where the first harmful event was not an overturn. Also excluded were cases with the following first harmful events: fire or explosion, immersion, gas inhalation, fell from vehicle, injured in vehicle, other non-collision, pedestrian, pedal cyclist, railroad train, animals, motor vehicle in transport, parked motor vehicle, other type non-motorist, thrown or falling object, other object not fixed, pavement surface irregularity, transport device used as equipment, vehicle occupant struck or run over by own vehicle, ridden animal or animal drawn conveyance. They were omitted because either air bags can not be expected to have an effect in some of these crashes, or others are so rare that modelling the fatality risks becomes too uncertain.

The collision file included collisions between two vehicles, cars or LTVs, not towing a trailer, excluding those where a vehicle was not in transport, or the manner of collision unknown.

VNTSC decoded the VIN and derived from it the type of restraint, including air bags, available. For vehicles of model years 1985 and later, it also assigned two codes developed by Dr. C. Kahane and Marie Walz of NHTSA; a four-digit car group code, which reflects the platform of which the vehicles are built, and a four-digit make/model code. Also, assigned were the vehicle weights corresponding to these codes. Where these weights were missing, we imputed them by either assigning the average weight for the same make/model over all model years, or the average weight for the car group.

For most analyses, cars of model years 1985 and later were used, first because of the availability of the Kahane codes and weights, second because practically none of the earlier model years had air bags; including them could have biased the results.

FARS contains all fatal crashes in the USA. GES is a sample of all police reported crashes; if expanded, it includes also all fatal crashes. Therefore, a combination of FARS and GES would double the number of fatal crashes. To avoid this, fatal crashes were dropped from the GES files when combining them with FARS.

GES is a complex sample. The country is divided into four geographic regions, and three types of land use, which combine to 12 strata (there is a further complication: for two self-representing PSUs, additional strata are created). Within each stratum, a number of PSUs are randomly selected. They are indicated in Table A-1 by their number, or an "x". This pattern has remained constant over the study period 1991-99. Within each PSU, either a sample of all crashes is taken, or first a sample of PJs is taken, and then within PJ crashes are sampled. The selection of most PJs has also remained constant over time, but some have been replaced by others in later years. At the last level of sampling, crashes are stratified by crash type into four strata, and within each of them police crash reports are sampled.

Table A-1 GES strata and PSUs. Regions, types, and the strata resulting from their cross-classification. Numbers show the PSUs used in this study. "x" indicates PSUs not used. States are shown for illustration; they enter the GES sampling plan only by defining regions.

		type		
region	state*	central city	suburban	other
Northeast	MA		x x	
	NJ			x
	NY	x x x	x x x	x
	PA	x	x x x	
Midwest	IL	72**	91	
	IN		x	
	IA			93
	MI	32	10 12 33	11 13
	MD		92	
	NE	74		
	OH	x	x	x
	WI		71	
South	AL		47	48
	FL	41	42	61
	KY			28
	MD		9	
	NC			43 44
	OK	64		
	TN		45 46	
	TX	49 63	50 62	51
	VA		x	
West	AZ		77	76 78
	CA	x	x x x	
	CO		75 94	
	NM		95	
	WA	82	81	

*States are shown for information only. They are not part of the sampling plan.
**Chicago is self-representing and treated as a separate stratum.

For this study, the VIN is a critical data item. FARS shows the VIN for nearly all cars and LTVs. In GES, the VIN is systematically missing: within a PSU, either VINs are given for the vast majority or even nearly all cases, or for none or only few. In the Northeast, VINs were missing in nearly all PSUs. Therefore, we dropped the GES cases from the Northeast region, and the FARS cases from the corresponding states from the data base; indicating this by “x” for the PSUs in Table A-1.

In the South, only one PSU, indicated by an “x” had two few VINs. It affects only the South - suburban stratum. GES cases from this PSU were omitted, and the weights (expansion factor) for the remaining 7 PSUs increased by a factor 8/7. This gives statistically valid estimates of police reported crashes in this stratum. The situation was similar in the three strata representing the Midwest. Here, in each of the strata 1/4 of the PSUs had missing VINs.

Therefore, the GES cases from these PSUs were dropped, and the weights for the other PSUs increased by a factor of 4/3.

In two of the Western strata, PSUs had missing data, all from California. One could have proceeded as in the South and Midwest, and obtained statistically valid estimates. However, California accounts for a high proportion of the crashes in the West, but it differs in many respects from the other Western states. Therefore, making estimates for the entire West only from the other states would probably have introduced strong biases.

Therefore, a new region was defined: the West excluding California. To make estimates for this new region, its strata, we obtained from NTASA crash numbers for the corresponding strata, and for California within these strata, and adjusted the GES weights accordingly.

To make error estimates, any statistical program requires at least two PSUs in each stratum. The stratum WxCA-central-city contained only one PSU, 82. To circumvent this difficulty, we created two artificial PSUs by separating the PJs in PSU 82 into two groups.

Our analyses used driver age and sex, car weight, and speed limit as independent variables. In FARS, values were rarely missing or unknown. In GES, this occurred more often[2]. These cases were simply omitted. This resulted in a systematic overestimation of fatality risks. Whether it biases the estimates of air bag effects, or the underlying mathematical models could have been determined only by very extensive analyses.

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[2]Dr. Daniel Blower of UMTRI noted that speed limit is missing in certain PSUs. In our data set, it is missing in Chicago.

Appendix B. Errors

The data and the results are subject to several kinds of errors:

- “gross errors” in data acquisition and coding
- missing information
- sampling errors in GES
- The random variability of the actual crash counts

Gross errors occur if crashes which are suppose to be reported are not, crashes which are not to be reported are included in the data files, and if information on the report form is wrong, e.g. age of the driver, speed limit, etc. Errors occur also in coding. In FARS, extensive quality control reduces such errors, in GES such checks are less thorough. Researchers usually ignore such errors, hoping that they will implicitly be included in the error estimates produced by the analytical techniques. In this study, this was also done. However, this assumption is not conceptually sound. The standard analytical techniques can capture only errors in the dependent variable. Errors in the independent variables require much more thorough studies.

In FARS, missing information is relatively rare; in GES it occurs frequently. Therefore, GES provides “imputed” values for many data items when the information is missing. They allow to make unbiased estimates of simple totals or means. However, it depends strongly on the details of the imputation and any patterns among the missing data whether this holds also for functional relations based on imputed values. Therefore, cases with critical information missing were omitted in this work. This results in an upward bias of the fatality risks estimated. Whether such biases show a pattern across crash types can not be assessed.

Most complex is the sampling error. The GES sampling plan consists of a stratification based on a cross-classification of geographical regions and land use, a first level of clusters, the PSUs, (one or several counties), a second level of clusters, (police jurisdiction within the PSUs,) and within the PSUs simple random sampling within four strata determined by crash type. Though these last strata are used in practice at the lowest sampling level, they are conceptually at the highest level.

The standard definition of the sampling error in such a complex sampling plan is that it reflects the variance among the results one would obtain if one took many different samples, following the same sampling plan, from the same population, e.g. all crashes in the entire US in one year. In our GES data base, the situation is slightly different. The overall sampling plan has remained constant over the period covered. The selection of the first level clusters has also remained constant over the period, and most of the selection of the second level cluster has also remained constant; only in recent years have in some PSUs different police jurisdiction been selected. That means that the contribution to the errors made by the choice of the PSUs, and most of that made by the choice of the police jurisdiction has remained constant.

Therefore, one can consider it as being more akin to a bias than to a random error. The only truly randomly varying element in our data base is the selection of the individual cases. This distinction could be important, because the error contributed by the selection of PSUs and PJs will not be reduced if GES data are accumulated over longer time periods; only the errors introduced by random sampling at the last stage will be reduced.

During a certain time period in one area, traffic crashes defined by a specific reporting criterion are a fixed number and as such not subject to statistical analyses. However, for research purposed they are considered realizations of random variables. Only this allows to answer questions such as whether a change from one year to another is "real", or whether an apparent relation between deaths and a certain variable is "real" or just due to chance. A common assumption is that the number of accidents of a certain type - be it defined as a broad class, or a very narrow one by the values of several pre-crash factor - is a Poisson-distributed random variable; sometimes more complete definitions are assumed.

Thus, nationwide counts of GES cases - all or only of certain types - as well as of FARS cases are to be treated as random numbers.

In the case of FARS, it is easy to deal with this issue: assuming that each FARS case is a realization of a binomial random variable which has a value of 0 or 1, - only cases with 1 appearing in the FARS file - and a certain expected value p allows straightforward statistical analyses.

In the case of GES, the situation is more complex. Again, one can assume that each crash is a random variable with value 0 or 1 (in this case, zero meaning that no crash occurs, 1 that a crash occurs, only the latter cases appearing in the GES files), with an expected value p. This means that if there are x crashes of a certain type, x is an estimate of the expected number m, and as a Poisson variable has the variance m, estimated by x.

The number x is not known, but GES gives an estimate x^. NHTSA publishes approximate estimates of the sampling error of x^. Under the Poisson assumption, x^ is an estimate of the variance of the random variable x. Comparing the "error" from Poisson variance with the sampling error, we find that the "error" resulting from the Poisson-variance is 8% of the sampling error for a count estimated to be 1,000, 1% for a count estimated to be 1,000,000. This means that for GES counts the random variability may be neglected relative to the sampling error. This was done in this study. However, this may not be true in some of the more complex analyses: if some relations are not, or only little affected by the "bias" component of the sampling error, and primarily by the case selection component, the random variability could contribute a higher percentage.

If one combines FARS and GES data into one file, how can one reconcile the different approaches to estimating errors? The following was done: first a new additional PSU stratum was created, which included all FARS cases. Since FARS cases have no PSU, they were randomly assigned to a number of newly created PSUs, ranging from 2 to 100. The statistical program used estimated errors from the differences of the estimates for the PSUs within each PSU stratum. In this case, this roughly approximated making estimates from the FARS data as if they had been Poisson distributed. With an increasing number of these fictitious PSUs from 2 to 100, the "error" calculated for the estimates increased initially rapidly, then move slowly, and finally remained practically constant. For the actual analyses, 10 fictitious PSUs were used; the effect of using more was negligible.

The software used, STATA, allows to estimate sampling errors considering the stratification, and the first level clustering; it does not provide for the effect of the second-level clustering at the PJ level. To explore the effect of this, we also performed some analyses using the PJs as if they were PSUs, thus greatly increasing their number. The effect on the error estimates was negligible. Therefore, we used the STATA program, using the actual GES PSUs, ignoring the second level clustering, and assigning the FARS cases to 10 fictitious PSUs.

Initially we had planned to use bootstrapping to make error estimates which allowed to incorporate all sampling stages of GES, to separate the effects of the GES quasi-bias from the random effect, and to consider the random nature not only of the FARS, but also of the GES cases. Though we found this conceptually feasible, the computational effect turned out to be prohibitive.

Appendix C. Statistical modelling

The ultimate purpose of the analyses was to estimate differences in the driver fatality risk in cars without and with air bags, using mathematical models to eliminate the effects of confounding factors, some of which are related to the presence or absence of an air bag. During the period studied, cars with air bags tended to be heavier - which reduces the fatality risk -, but heavier cars tend more often to be driven by men than by women, and by older drivers than by younger drivers - both of which tend to increase the fatality risk. Speed - for which the speed limit was used as rough proxy - increases the fatality risk. Though it does not seem to be correlated with the presence of an air bag, it was included in the analysis because it has a very large effect on the fatality risk; including it should decrease the variance of the estimates.

Figure C-1 shows the distributions of car weights in the single car crashes and collisions between two cars studied, by presence of air bags. Cars with no air bag have a median weight of about 2,700 lb, cars with air bags about 3,000 lb. There were practically no cars without air bags above 4,100 lb, but there were cars with dual air bags heavier than 4,500 lb. On the other hand, few cars with air bags weighed less than 2,000 lb, different from cars without air bags.

There are basically three ways to estimate the effect of air bags:

1) Developing a model for all cars, with and without air bags, which includes a term for the presence of an air bag (and perhaps interaction terms between the presence of an air bag and other factors). The air bag term would reflect the effect of the air bag, and any interaction terms would show how its effect depends on other factors. This approach was not use because of the correlation between the presence of an air bag and car weight. Their effects could not be credibly separated.
2) Developing separate models for cars with, and without air bags. The difference (or ratio) of these two models would show the effect of the air bag, and how it depends on the terms which differ between the models. At first glace, the effect of the correlations between air bag presence and confounding factor seems to be reduced, but a second order effect can remain if the weight terms in the models do not have the correct mathematical form. A more practical problem was that sometimes terms in the model were ambiguous: replacing one interaction by another, or changing the shape of a relation often did not change the fit of the model, but omission of the term would have done it. In such a situation, the difference between two models could be quite ambiguous. For instance, some choices of interaction terms could have resulted in several interactions in the difference of the risks, whereas with another choice the difference of interactions would have become negligible. Also, the errors of the estimated coefficients, based on fewer cases, would be larger than in approach 1. We experimented with this approach and abandoned it.

3) Develop a model for cars without air bags, and use it to predict for each crash involved car with an air bag which risk its driver would have faced, if he had been in car without an air bag, using the same pre-crash factors. Analyzing the actual driver deaths and the calculated risks gives estimates of air bag effects, and how they depend on the studied factors. This approach has none of the potential biases of approach (1), and not the ambiguity of interaction terms noticed in approach (2), nor the increase in the errors of the coefficients, resulting from the larger number of coefficients. Approach (3) was used.

Modelling of the fatality risks was based on the combined FARS and GES (omitting the fatal cases) files, with a dependent 0/1 variable representing driver survival or death, and expansion factors of 1 for the FARS cases. Mathematical functions for the probability of driver death were used, and their coefficients estimated by the maximum likelihood technique. Models with different mathematical functions of the independent variables were explored, and those fitting "best" selected. Independent variables were driver age and sex, car weight[3], and the speed limit as rough indicators of travel speed. Preliminary work in this study showed that in a first approximation a multiplicative model of univariate functions of the three continuous, and the single categorical (sex) variables represented the probabilities better than additive models, and that the univariate functions were highly nonlinear. The effect of the speed limit was nearly exponential, with 55 mph usually deviating from an otherwise smooth relation. The effect of driver age was usually a slow increase up to ages around 50 to 60 years and a very rapid nonlinear increase with higher ages; for some crash configuration there was a decrease with age for the youngest drivers. The apparent effect of age is a combination of two physical effects: the physical vulnerability of humans, as reflected in the fatality risk for injuries of given severities, increases with age. On the other hand, actual travel speed, relative to the speed limit is likely to decrease with increasing age, at least in the younger age range. For car weight the best first order approximation of its effect on the fatality risk was (weight) ^a, with a negative constant a. For the effect of driver sex - again, its apparent effect is probably a composite of two physical effects: the better survival of women, and probably lower speed relative to the speed limit - a constant factor is a first approximation.

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[3]Initially, for collisions, models including both drivers' ages and sexes, and both cars' weights were used. This made the analyses much more laborious than when only the case car's variables were used. Since there were no correlations between the variables relating to the two cars, omitting those for the "other" should not much bias the estimates of the coefficients of the model, though it might increase their standard error.

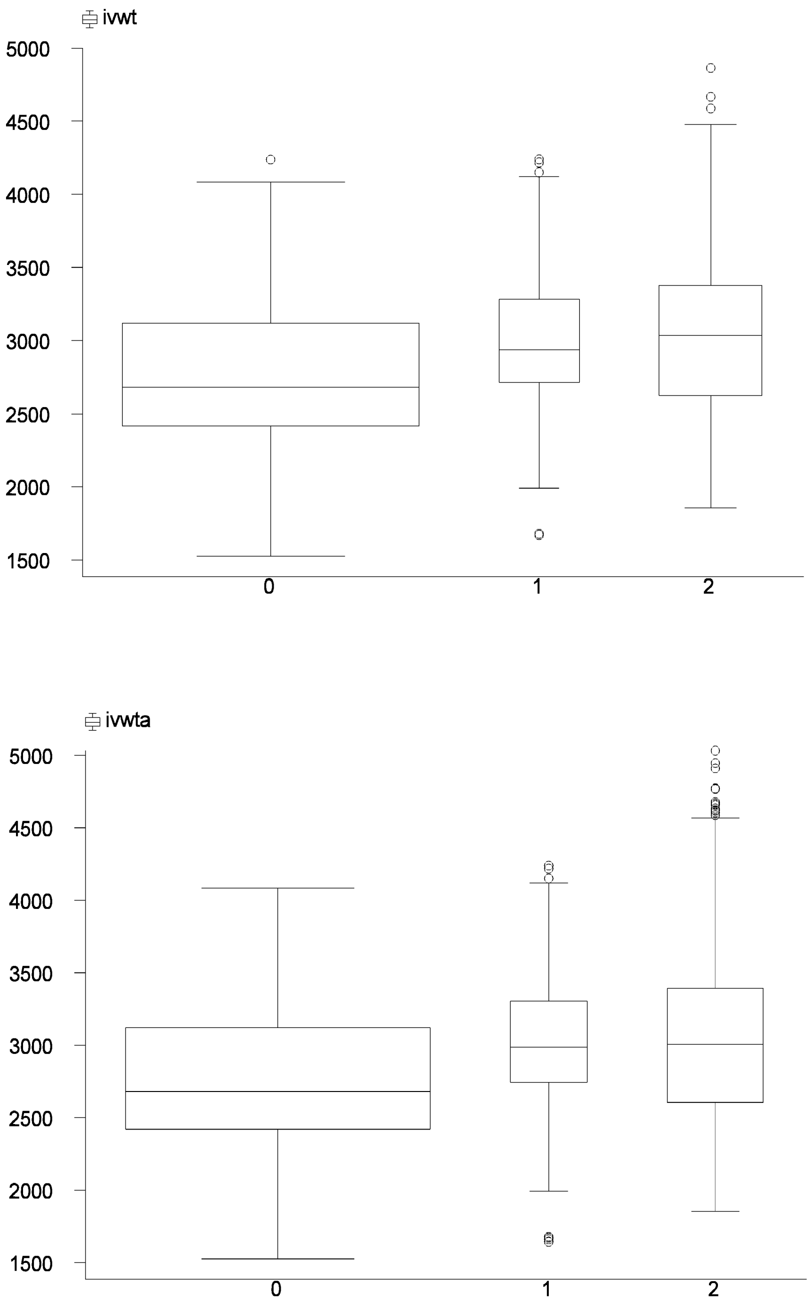

Figure C-1 Box and Whisker plots of car weight, in single car crashes (top) and collisions between cars, by number of air bags in car (0 = none, 1 = driver only, 2 = dual). The widths of the boxes are proportional to the number of crashes.

The resulting model had the following structure:

p(death) = a ∗weight^b ∗exp(c ∗age) ∗exp(d ∗splimit) ∗(e ∗female) (C-1)

or

p(death)=exp(A+B ∗log(weight)+(c ∗age+d ∗ splimit+e ∗female) (C-2)
=exp(L(weight,age,splimit,female))

To fit such a model would have required more work than to fit the common logistic model

p(death)=exp(L)/(1+exp(L)) (C-3)

for which elaborate programs are available in statistical software packages[4]. Because in our problem p(death) is of the order 1/100, and only in rare cases about 1/10, the difference between the logistic model (C-3) and the log-linear model (C-2) is negligible. It should be emphasized that we did not choose the logistic model because its functional form is preferable - which is not the case - but only because it is a sufficient approximation to our preferred model, but with more readily available computer programs.

As a first approximation, a model like (C-2) was fitted, and its fit of the data checked. This was done by plotting the actual risks for groups of cases, and comparing them with the modelled risks for these groups, versus the variables in the model. In practically all cases, there were systematic deviations in relation to weight. Adding a quadratic and even an additional cubic term did not result in an acceptable fit. However, introducing a "kinky" relation by adding a variable (age-a1) ∗ (age>=a1), where (age>=a1) equals 1 if the inequality is satisfied, zero if not, improved the fit greatly and often sufficiently. The values of a1 was obtained by trial and error; typically a value between 45 and 65 years was best. Sometimes, a second, similar term had to be added, sometimes also with regard to young age. The same was done with respect to car weight and speed limit. For the latter, usually a categorical variable for the speed limit 55 mph had to be added.

In the next step, interactions between the variables were explored. Several approaches were used. The simplest and most formalistic was to add the product of two variables as a new variable and see whether it improved the model. A variant of this approach is to plot residual versus this new variable (or to plot residual versus the residual of the product against a model regressing it on the other variables in the model). Sometimes this approach showed that not the product itself, but a related function might improve the model best, e.g. (X1-a1) ∗ (x1>=b1) ∗ (x2-a2) ∗ (x2>=b2) Another approach was to aggregate each of the variable whose interaction was being explored into 2, 3, or 4 categories, and create a bivariate table of the actual and modelled risks. This gave sometimes guidance to the best form of the interaction term. The most detailed

[4]We used the logit and svylogit procedures of STATA.

approach was to fit several models, each for a narrow range (sometimes several sets of models with overlapping ranges) of one variable. Checking for a trend of the coefficients of the other variables against the values of the selected variables sometimes gave directly the interaction terms. Similar procedures were use to search for interactions of the variables.

Checking the goodness of the fit was mainly subjective. One reason was that by conventional test even the most primitive models were extraordinarily good, even if systematic deviations were quite obvious. The reason is that the majority of crashes cover only a narrow range of car weights, a somewhat wider, but still narrow range of driver ages, and that about half of the deaths occurred at speed limits of 55 mph. Therefore, standard test are heavily influenced by the goodness of fit in the middle ranges, and largely ignore even large and systematic deviations toward the end of the scales e.g. car weights above 3,500 or below 2,400 lbs, or ages above 60 years. For our purpose, however, it is better to have a function that approximates the data uniformly over the full range, than one that only minimally increases the fit for the most common cases (but weight this heavily because of their large numbers) but worsens the fit for the other cases. To some extent, we also used the error of a coefficient as estimated by the program. In marginal cases, large error lead to rejection of the term.

Errors obtained by the program should not be interpreted in the conventional manner. First, there are the problems discussed in Appendix B. Then, the extensive search for models giving a “best” fit of the data violates the basic assumptions for testing the significance of model coefficients, as is well known but usually ignored. Therefore, we call the error estimates “non-standard” errors, to warn the reader against taking them literally.

The graphical analyses revealed an interesting point. Plots versus driver age were usually smooth, and using different groupings of cases to form averages which could be plotted changed the resulting cases only little. Plots versus vehicle weight behaved differently. Point-to-point fluctuations around clear overall trends were large, and different groupings by weight gave sometimes very different average points, even if overall trends appeared to be the same. Closer examination showed that some groupings concentrated certain makes/models into one point, whereas others distributed them over several points. That did sometimes lead to large residuals. There may be several reasons for this. One is that there might be substantial differences in crashworthiness between makes/models of similar weights. Another is that certain make/models may be targeted at drivers who get into more severe accidents than drivers of other cars of similar weights. Future work should explore such possibilities by adding a categorical variables for each of at least the most common make/models. A difficulty is to set a threshold. With too high a threshold, adding only very few make/model terms, the effect would not be eliminated. With too low a threshold, there would be very many make/model terms which could no longer reflect only specific make/model characteristic different from weight, but capture much of the weight effect, and greatly increase the error of any remaining weight term.

Appendix D. Simplistic estimates of air bag effectiveness

In chapter 2, we made some very simplistic estimates of air bag effectiveness based on the actual number of FARS and of GES cases, ignoring expansion factors and potentially confounding factors. Surprisingly, these estimates were sometimes close to those obtained by the more sophisticated analyses.

In this Appendix, we present estimates which are one level better: the GES expansion factors were applied to the GES cases, but potentially confounding factors were still ignored. For each of the eight crash types selected (Table D-1), the driver fatality risks in cars with air bags, and in cars without air bags were calculated. Their ratio gave the simple estimate of air bag effectiveness. Table D-1 shows the estimates, comparing them with the more sophisticated estimates (section 3.2).

Table D-1. Estimates of air bag effectiveness (percent diverse fatality reduction) by crash type, based on models accounting for confounding factors (chapter 2), and on simple comparisons of fatality risks in cars with and without air bags.

Crash Type	Estimates based on models	 simplistic
Collisions between two cars		
all impacts	42	48
frontal impact	45	54
right side struck by front of other car	29	43
left side struck by front of other car	19	26
Single car crashes		
all impacts	33	30
frontal impacts	44	40
right side impact	11	10
left side impact	19	2

There are systematic differences. For collisions between two cars, the simple estimates are always higher, by between 6 and 14 percentage points. Such a consistent difference may plausibly be due to the lack of control: e.g. in the earlier years, air bags were available only in heavier cars, which had lower risks. Therefore, the simple estimates should overestimate the risk reduction resulting from air bags.

For single car crashes, the difference is in the opposite direction: the simple estimates are always lower than the model-based ones: by 1 to 4% percentage points, and even17 percentage points for left side impacts. There is no obvious plausible explanation why this should be so. That the effect of car weight on the fatality risk is smaller in single car crashes than in collisions between cars could explain a smaller bias than in collisions between cars, but not a reversal of the sign.

Figures D-1 through 16 show estimates by calender year of the accident. For each year, the first figure shows the driver fatality risks in cars with air bags (broken line), without air bags (solid line), and for both combined (dotted line). The second figures show the ratios of the risks in cars with, and in cars without air bags. Also shown is a straight line fitted to these ratios, without any weighting, just to show more clearly whether a time trend is suggested by the points.

In the odd-numbered figures one can see that in the earlier years the dotted line, representing all cars, is close to the solid line representing cars without air bags. In the later years, the dotted line is roughly half-way between the two other lines, reflecting the increasing share of cars with air bags of the car population.

In 4 of the odd-numbered figures the risk in air bag cars is always lower than in non-air bag cars; in one additional one it is lower except for one year when the risks are equal, and in another one the risk is air bag cars is always lower with the exception of one year where it is slightly higher. For left side and right side impacts in single car crashes, the differences between cars with out and with air bags vary in their signs, suggesting great uncertainty of the estimates.

The ratio of the risks in cars with air bags and in cars without air bags gives an estimate of the apparent effect of the air bags. The even-numbered figures show these ratio. A fairly consistent pattern appear: in all but one case (left side impacts in collisions) the ratios show downward trend with time, indicating an increasing effect of air bags - sometimes a substantial increase. Surprising is, however, that in both types of side impacts in single car crashes the risk in air bag cars is in the earlier years much higher than in air bag cars.

Such unexpected patterns can result from various confounding factors. They suggest that it is important to account for the effect of confounding factors if one wants realistic estimates of air bag effect.

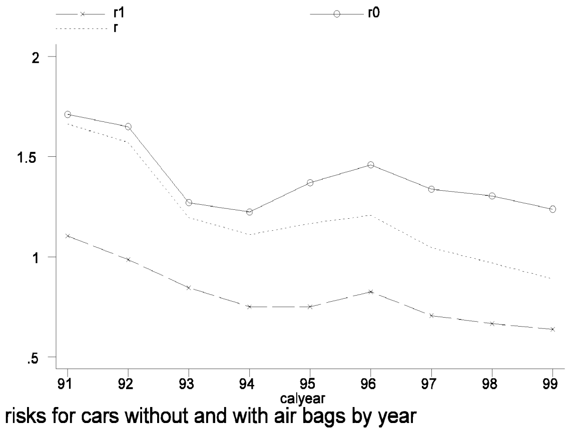

Figure D-1. Fatality risks (per 1,000 involvements) for drivers of cars without air bags (solid line), with air bags (broken line), and without respect to presence of air bags (dotted line), versus year of crash. Collision between two cars.

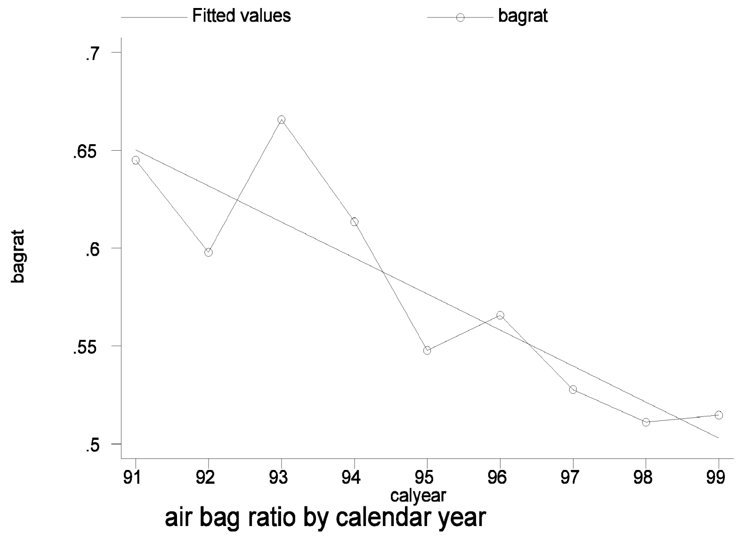

Figure D-2 Ratio of the fatality risks for drivers of cars with air bags, and without air bags, versus year of crash. The straight line is fitted to the points without any weighting. Collisions between two cars.

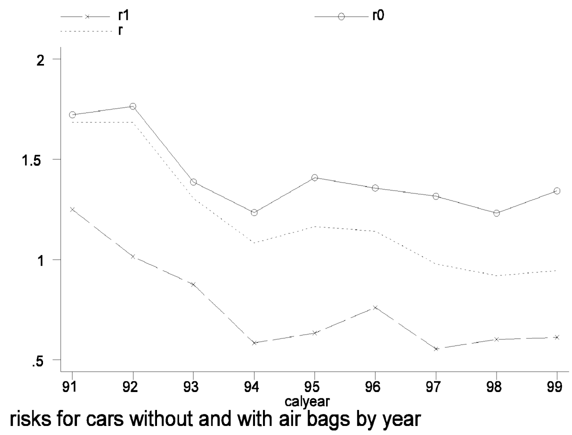

Figure D-3. Fatality risks (per 1,000 involvements) for drivers of cars without air bags (solid line), with air bags (broken line), and without respect to presence of air bags (dotted line), versus year of crash. Cars with frontal impact in collisions between two cars.

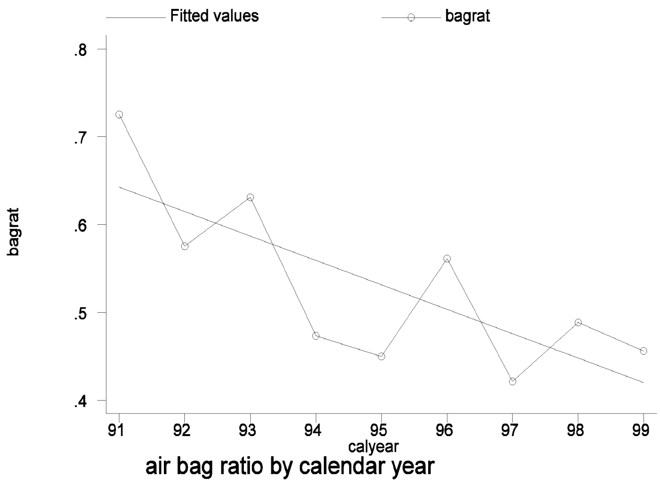

Figure D-4. Ratio of the fatality risks for drivers of cars with air bags, and without air bags, versus year of crash. The straight line is fitted to the points without any weighting. Cars with frontal impacts in collisions between two cars.

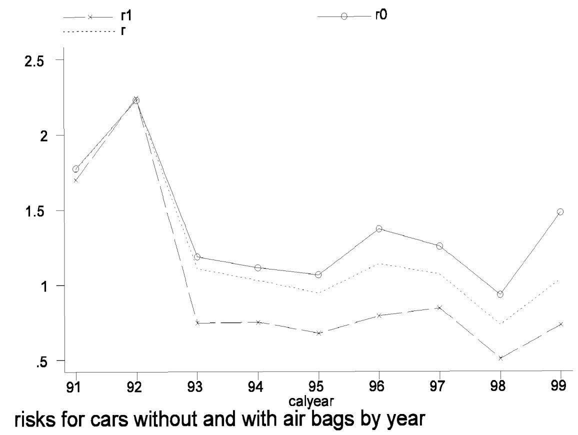

Figure D-5. Fatality risks (per 1,000 involvements) for drivers of cars without air bags (solid line), with air bags (broken line), and without respect to presence of air bags (dotted line), versus year of crash. Cars with right side struck by the front of another car in collisions between two cars.

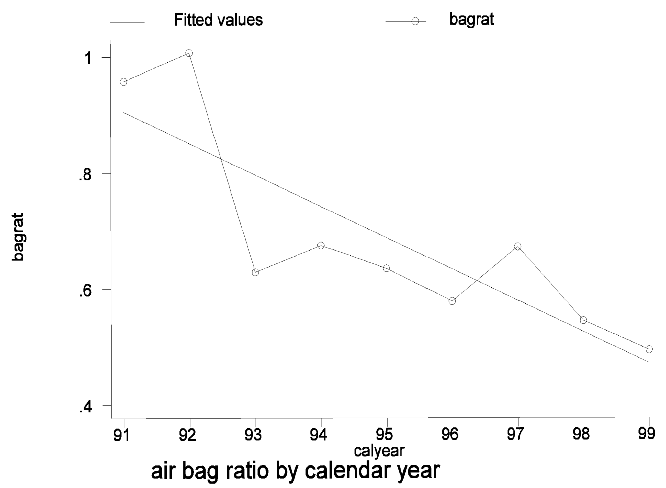

Figure D-6. Ratio of the fatality risks for drivers of cars with air bags, and without air bags, versus year of crash. The straight line is fitted to the points without any weighting. Cars with right side struck by the front of another car in collisions between two cars.

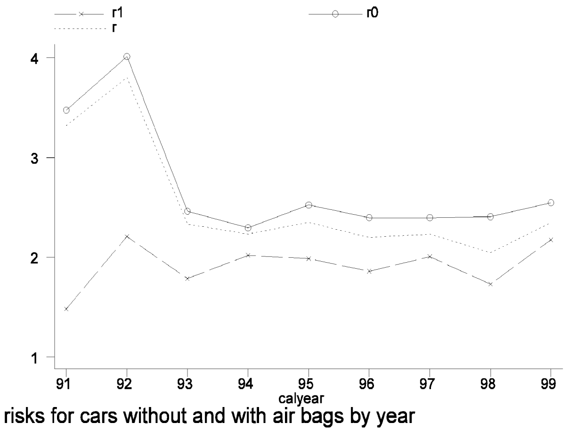

Figure 7. Fatality risks (per 1,000 involvements) for drivers of cars without air bags (solid line), with air bags (broken line), and without respect to presence of air bags (dotted line), versus year of crash. Cars with left side struck by the front of another car in collisions between two cars.

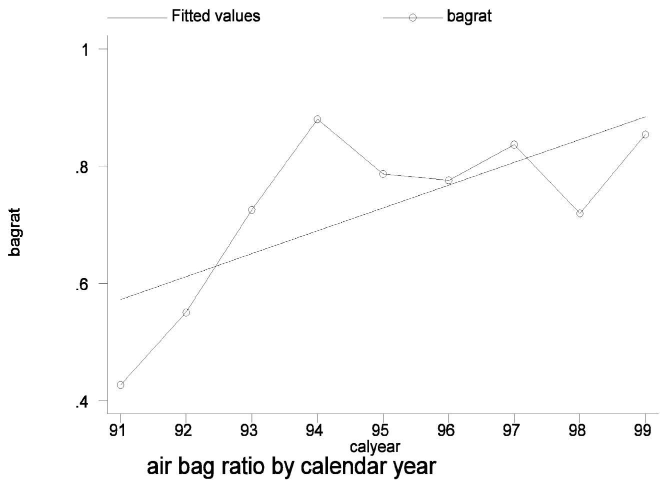

Figure D-8. Ratio of the fatality risks for drivers of cars with air bags, and without air bags, versus year of crash. The straight line is fitted to the points without any weighting. Cars with left side struck by the front of another car in collisions between two cars.

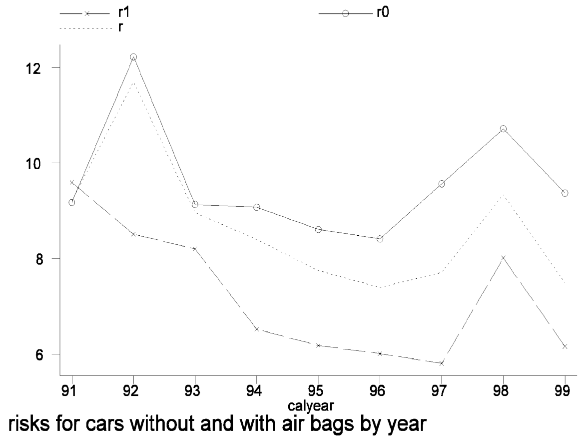

Figure D-9. Fatality risks (per 1,000 involvements) for drivers of cars without air bags (solid line), with air bags (broken line), and without respect to presence of air bags (dotted line), versus year of crash. Single car crashes.

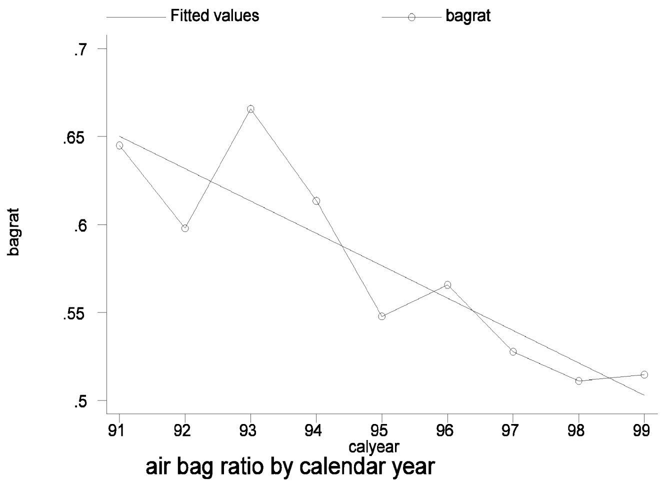

Figure D-10. Ratio of the fatality risks for drivers of cars with air bags, and without air bags, versus year of crash. The straight line is fitted to the points without any weighting. Single car crashes.

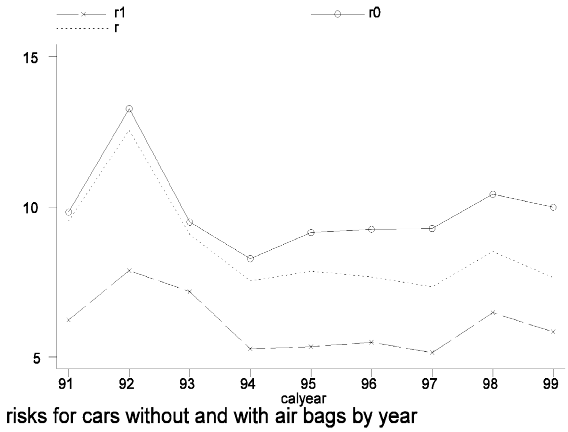

Figure D-11. Fatality risks (per 1,000 involvements) for drivers of cars without air bags (solid line), with air bags (broken line), and without respect to presence of air bags (dotted line), versus year of crash. Frontal impacts in single car crashes.

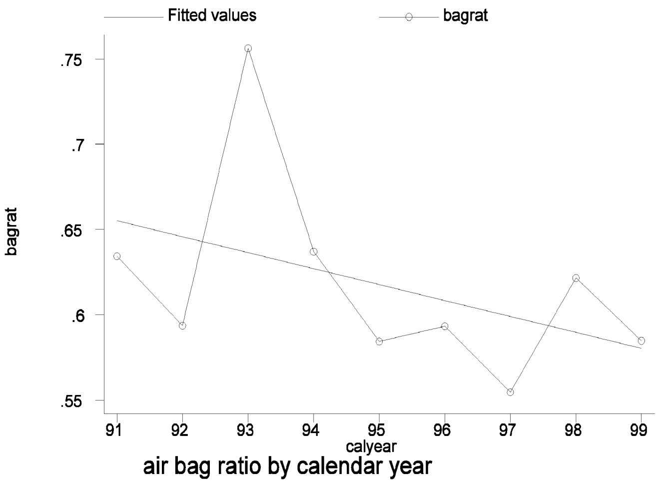

Figure D-12. Ratio of the fatality risks for drivers of cars with air bags, and without air bags, versus year of crash. The straight line is fitted to the points without any weighting. Frontal impacts in single car crashes.

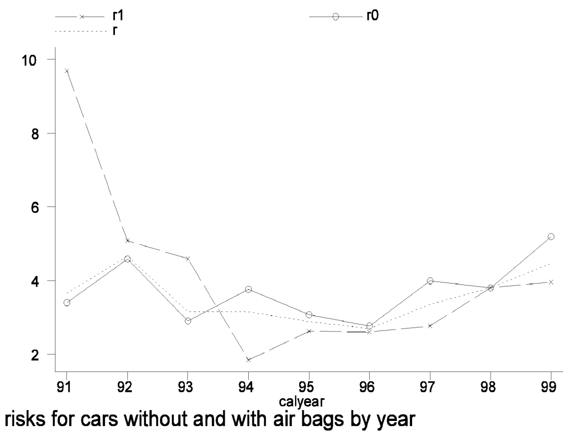

Figure D-13. Fatality risks (per 1,000 involvements) for drivers of cars without air bags (solid line), with air bags (broken line), and without respect to presence of air bags (dotted line), versus year of crash. Right side impacts in single car crashes.

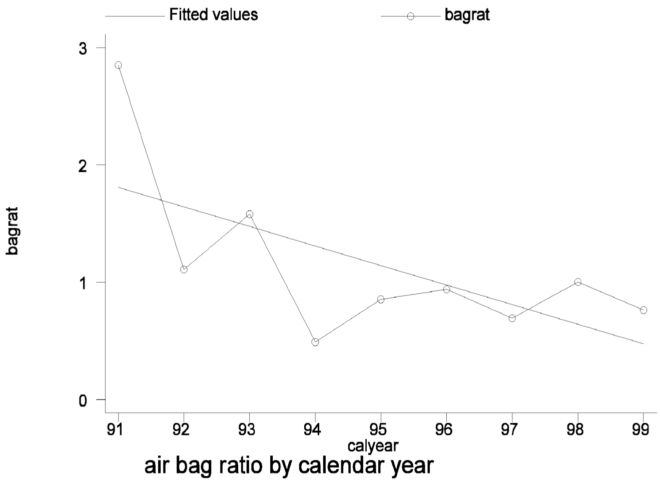

Figure D-14. Ratio of the fatality risks for drivers of cars with air bags, and without air bags, versus year of crash. The straight line is fitted to the points without any weighting. Right side impacts in single car crashes.

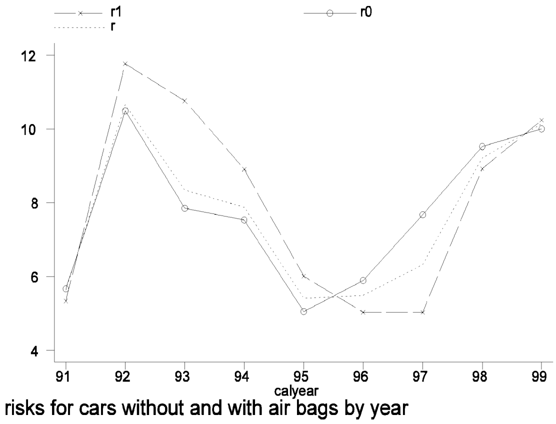

Figure D-15. Fatality risks (per 1,000 involvements) for drivers of cars without air bags (solid line), with air bags (broken line), and without respect to presence of air bags (dotted line), versus year of crash. Left side impact in single car crashes .

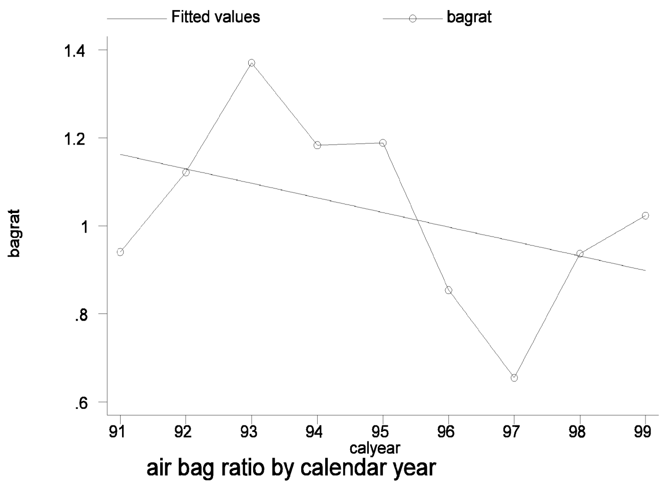

Figure D-16. Ratio of the fatality risks for drivers of cars with air bags, and without air bags, versus year of crash. The straight line is fitted to the points without any weighting. Left side impact in single car crashes.